RTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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SCIENCE AND ENGINEERING

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July 13, 1965 to June 30, 1967

U.S. DEPARTMENT OF COMMERCE
C. R. Smith, Secretary

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Robert M. White, Administrator

April 1968

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FOREWORD

This publication is the first consolidated overview of the Environmental Science Services Administration, ESSA, since its establishment on July 13, 1965. It represents a unified study replacing annual publications previously issued separately by the Weather Bureau, the Coast and Geodetic Survey, and the Central Radio Propagation Laboratory of the National Bureau of Standards.

Robert M White

ROBERT M. WHITE
Administrator

EDITORS' PREFACE

This publication discusses science and engineering in ESSA during FY 66 and FY 67. These activities have been reviewed deliberately within the two-dimensional framework of ESSA missions and objectives, rather than in the traditional terms of organizational structure. This framework is represented by a Program Analysis Matrix (see below), which contains a set of elements encompassing all ESSA science and engineering operations. The purpose is to present ESSA from a multidisciplinary point of view, which emphasizes the application of the methods, procedures, and techniques of various interrelated scientific disciplines to the solution of major problem areas in environmental science and technology.

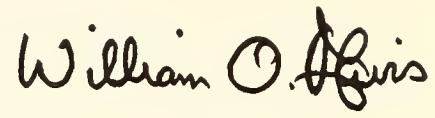
It is important to note that this study deals exclusively with those activities pursued during the first 2 years of ESSA's existence. Major organizational changes occurred during this period, and they have continued to occur. References made to organizational relationships on the component level are given as they existed during the reporting period and are depicted in the accompanying organizational chart. Hence, the discussion is oriented to function, not organization.

The study is divided into seven chapters, each of which deals with various aspects of the science and engineering programs of ESSA: Organization, products, accomplishments of a singular nature, description of the environment, environmental prediction and warning, and supporting activities. A compilation of papers and publications is also included.

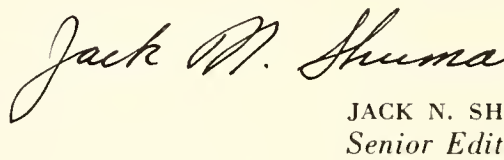
The preparation of a publication of this scope is always a collective endeavor, involving the participation of many individuals. However, we are especially indebted to Robert R. Walter, ESSA Management Intern, who provided outstanding editorial assistance and technical support.

The assistance of Jack Gertzog in assembling and collating the initial inputs for this survey is greatly appreciated.

We would also like to thank the following for their efforts in bringing this publication to completion: Albert Carlin, John Smiles, Louis E. Leipold, Frank Farquhar, Sarah Kroll, Max M. Chesy, Edward W. Koehler, Exum Roberts, William E. Jones, James V. Schick, Francis X. Oxley, Joan M. Genchi, Won Joo Leonard, Richard Estes, Jack Rausch, William Welch, Charles Cotten, Lila Paavola, and Helen Hoener.



WILLIAM O. DAVIS
Editor-in-Chief



JACK N. SHUMAN
Senior Editor

Environmental Areas and Interfaces	Environmental Description and Understanding	Environmental Prediction and Warning	Environmental Engineering Activities
The Earth and Its Fields	Geomagnetism Teleseismology Geodesy	Earthquake Mechanisms	Geomagnetic Engineering Geodetic Engineering Engineering Seismology
Earth and Ocean	Marine Geology and Geophysics Hydrography and Bathymetry Land and Sea Interaction	Tsunami Warning Research	Ocean Engineering
Earth and Atmosphere	Aeronautical Charting Hydrology	River and Flood Tropospheric Telecommunications Tropospheric Remote Sensing Radio Meteorology	Hydrologic Engineering Tropospheric Telecommunications Engineering
Ocean and Atmosphere	Physical Oceanography Sea-Air Interaction Geophysical Fluid Dynamics Atmospheric Physics and Chemistry Climatology	Systems Development Satellite Meteorology Numerical Prediction Extended Range Forecasting Hurricane Research Severe Storms Research	Climatological Engineering Clear Air Turbulence Environmental Pollution Turbulence and Diffusion Weather Modification
Atmosphere and Ionosphere	Meteorological Statistics Aeronomy		
Ionosphere and Earth	Aeronomy	Ionospheric Telecommunications Prediction	Ionospheric Telecommunications Engineering
Ionosphere and Space	Aeronomy	Space Disturbance Forecasting	
Supporting Facilities, Services, and Development Activities:		Development and Test Facilities Stations and Platforms Environmental Sensors	Communications Networks and Systems Computation and Data Processing Facilities Archiving

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1 MISSION, MAJOR OBJECTIVES, ORGANIZATION, AND RESOURCES

The Environmental Science Services Administration (ESSA), formed from previously existing components within the Department of Commerce, was established on July 13, 1965, with the implementation of the President's Reorganization Plan No. 2 of 1965. The formation of ESSA brought together the functions of the Weather Bureau (WB) and the Coast and Geodetic Survey (C&GS) which became two of the major elements of the new agency. At the same time, the Institutes for Environmental Research (IER), the Environmental Data Service (EDS), and the National Environmental Satellite Center (NESC) were also created. Finally, the Central Radio Propagation Laboratory was transferred to ESSA from the National Bureau of Standards and became the Institute for Telecommunication Sciences and Aeronomy (ITSA), joining ESSA's Institutes for Atmospheric Sciences, Earth Sciences, and Oceanography. The combination of these functions in a single agency provided for the first time the specialized knowledge, equipment, and responsibility needed to conduct a systematic study of man's physical environment and to develop the capability for an integrated environmental service program.

ESSA'S MISSION

In announcing the establishment of ESSA, President Johnson described it as: "A single national focus to describe, understand, and predict the state of the oceans, the state of the upper and lower atmosphere, and the size and shape of the earth."

A more detailed description of the Mission and functions of ESSA was given by the Secretary of Commerce in Departmental Order 2A:

"To ensure the safety and welfare of the public, to further the Nation's agriculture, industry, transportation, and communications, and to assist those Federal departments and agencies that are concerned with the national defense, the exploration of outer space, the management of the Nation's mineral and water resources, the protection of the public health against environmental pollution, and the preservation of the Nation's wilderness and recreation areas, the Administration shall perform the following functions:

a. Observe and collect comprehensive data about the state of the oceans and inland waters, of the upper and lower atmosphere, of the space environment, and of the earth;

b. Communicate, correlate, process, and analyze all such environmental data;

c. Provide and disseminate information about the state of the oceans and inland waters, of the upper and lower atmosphere, of the space environment, and of the earth, and prediction of their future states;

d. Prepare and disseminate warnings of all severe hazards of nature to all who may be affected;

e. Provide nautical, aeronautical and telecommunications charts and related publications and services;

f. Operate and maintain a system for the storage, retrieval, and dissemination of data relating to the state of the oceans and inland waters, of the upper and lower atmosphere, of the space environment, and of the earth;

g. Explore the feasibility of modification and control of environmental phenomena;

h. Coordinate Federal meteorological services and supporting research;

i. Acquire, analyze and disseminate data and perform basic and applied research on the propagation of electromagnetic waves, on the nature of electromagnetic noise and interference, and on methods for the more efficient use of the electromagnetic spectrum for telecommunications purposes; and prepare and issue predictions of electromagnetic wave propagation conditions, and warnings of disturbances in those conditions, acquire, analyze and disseminate data and perform basic and applied research on the propagation of sound waves to great distances through the atmosphere and other media, and on geophysical interactions between sound waves and other geophysical phenomena; and

j. Perform research and development relating to the oceans and inland waters, the lower and upper atmosphere, the space environment, the earth, and the use of

the electromagnetic spectrum for telecommunications purposes, as may be necessary or desirable to develop an understanding of the processes and phenomena involved; and research and development relating to the observation, communication, processing, correlation, analysis, dissemination, storage, retrieval, and use of environmental data as may be necessary or desirable to permit the Administration to discharge its responsibilities."

Although the preceding statements are quite broad in scope, ESSA's responsibilities do not extend to include all areas of the environment. For example, ESSA's mission does not include the study of the biological aspects of the environment or the location and identification of natural resources. Moreover, even in the broad context of the physical environment, where ESSA does have assigned functions, other Federal agencies have important responsibilities related to their own specific missions.

MAJOR OBJECTIVES

To undertake missions of such broad scope with limited resources, it becomes necessary from time to time to differentiate and emphasize specific objectives within ESSA's broad policy areas. This specific allocation of effort and resources maintains a balanced program and assures a maximum level of progress.

First and foremost must be the continuing objective of performing and improving the essential services to the public which are the traditional responsibility of ESSA's major line components; and, the selection of specific major objective areas must be viewed as being in support of this continuing objective.

At the present time, major emphasis is being placed on the following areas: World weather programs; the nationwide Natural Disaster Warning System (NADWARN); weather modification; environmental pollution; forecasting the marine environment; and the optimum utilization of the radio frequency spectrum.

World Weather Programs

In 1966, President Johnson called upon the United States to exercise a role of leadership in furthering the world weather program. This program includes the conduct of a comprehensive program of research and development on the general circulation of the atmosphere and the development of a World Weather Watch system.

This system is defined as follows by the World Meteorological Organization (WMO):

> "The World Weather Watch is a system for the observation, collection, processing, and dissemination of global weather data using the most recent developments in modern space communication, data processing, and meteorological and instrumentation technology. Its purpose is to remedy age-old deficiencies in our weather operations which now prevent meteorological science from giving us weather predictions of longer range, greater accuracy, and greater usefulness. It is an international undertaking aimed at the improvement of weather service for all nations of the world."

The President directed that the Department of Commerce, specifically ESSA, provide a focal point to coordinate United States efforts in this program, initiate service improvements in the existing weather system for which the United States assumes responsibilities, and continue the development of new technology as it relates to responsibilities under existing authority.

ESSA considers that the world weather program goals can be achieved if the following objectives are met:

- Establishment of a global weather observation and forecasting system (World Weather Watch), which would treat the world atmosphere as a single physical system;
- Creation of an international program of research in which specialized worldwide observational programs would proceed simultaneously with theoretical studies directed toward understanding the general circulation of the global atmosphere;
- Development of mathematical techniques for forecasting the weather up to 2 weeks in advance.

The Nationwide Natural Disaster Warning (NADWARN) System

The NADWARN System was described in detail in the NADWARN Report published in October 1965. Resulting from an interagency study of natural disasters, the report recommended the creation of an integrated national disaster warning system which would identify and predict environmental hazards, rapidly disseminating appropriate warnings to those potentially affected. It further recommended a system of detection, communication, community education, and preparedness, and indicated critical areas for research and development. The initial phases of this system will involve the establishment of additional statewide teletypewriter networks; of extended river forecast capabilities; of research to improve the forecasting of near-space environmental disturbances, hurricanes, tornadoes, floods, and severe local storms; the extension of radar coverage and the expansion of the tsunami warning system.

Meanwhile, within the limitations of budgetary resources, the major line components of ESSA have worked to put into effect other recommended parts of the NADWARN System. These actions involve the connection of 135 Weather Bureau stations to the nationwide Natural Warning System Network of the Office of Civil Defense; the publication of new brochures concerning safety precautions to be taken when tornadoes and hurricanes occur; and standardization of terminology so that the news media and the public will gain greater appreciation of the serious nature of warning bulletins. In addition, ESSA has updated and republished a model hurricane plan for use by communities and has strengthened communication facilities used to deliver seismic sea wave (tsunami) warnings. Finally, the Fire Weather Service has been expanded, and a National Earthquake Information Center organized.

Weather Modification

During this reporting period, two significant reports led to an even broader interest in the possibility of modifying or controlling the weather; the National Academy of Sciences–National Research Council (NAS/NRC)

Publication No. 1350, "Weather and Climate Modification Problems and Prospects" and the National Science Foundation Report of the Special Commission on Weather Modification (NSF 66–3) "Weather and Climate Modification."

Largely in response to these reports an ad hoc ESSA group prepared "An Outline of a Proposed 5-Year Plan in Weather Modification" which defined the purpose and scope of this major objective area. In this case, the service functions to be performed are all in the future; the objectives at this time are entirely in the research area. Areas to be investigated include: Hurricane and severe storm modification, rainfall augmentation, redistribution of heavy snow fall, and lightning and hail limitation.

Environmental Pollution

Problems of environmental pollution were highlighted by three reports which appeared during this reporting period: The Report of the President's Science Advisory Committee (PSAC), "Restoring the Quality of Our Environment;" the American Association for the Advancement of Science (AAAS) Report "Air Conservation;" and a study by the National Academy of Sciences–National Research Council (NAS/NRC) "Waste Management and Control." These reports reviewed the problems created by pollution and indicated the necessity for action.

On the basis of the PSAC Report, the President requested that appropriate departments and agencies consider its recommendations and report on possible approaches to the problems cited in the report. In response to this request, ESSA prepared a 5-year plan defining its objectives in dealing with the problems of environmental pollution. ESSA's role is primarily one of specialized support to other agencies with air and water pollution abatement and control missions.

Marine Environmental Activities

A systematic study of activity began near the close of FY 66 following the release of the PSAC report, "Effective Use of the Sea," and expanded with the enactment of the Marine Resources and Engineering Development Act on June 17, 1966, and the subsequent establishment of the Marine Resources and Engineering Development Council. ESSA's marine-related programs are directed toward observing and interpreting the effects of the world's oceans on the total environment in order to predict, modify, and effectively utilize the environment. This entails:

- The development of systems to obtain accurate observations of oceanic features and their distribution in time and space, processes within the sea, and interactions between the ocean, atmosphere, and solid earth;
- The design of systems to rapidly accumulate, process, and disseminate environmental data;
- The development of analytical techniques and methods to evaluate, interpret, and predict environmental conditions;
- The determination of the most effective means for presenting environmental information in its most usable form; and
- The issuance of timely warnings of environmental hazards.

Electromagnetic Spectrum Utilization

The requirements of the United States for telecommunications in both civilian and military applications are increasing rapidly. The portion of the electromagnetic spectrum utilized for these purposes is already crowded, and the Nation as a result is experiencing a shortage of assignable frequencies—a "silent crisis," as is so strongly emphasized in a report prepared in October 1966 by the Telecommunications Panel of the Department of Commerce Technical Advisory Board.

ESSA is the central Federal agency responsible for alleviating this problem. Within the scope of this responsibility, ESSA's Institute for Telecommunication Sciences and Aeronomy is conducting research to improve the technical basis for the more efficient utilization of the telecommunications environment. Other objectives are in the process of being defined and this list of major objectives may be expected to grow and change in future years.

PRODUCTS AND SERVICES

ESSA's services, and the science and engineering programs which support these services, fall in four broad categories:

- Describing and understanding man's environment;
- Environmental prediction and warning;
- Environmental engineering services and activities;
- Supporting services and facilities.

These functions are officially designated as Department of Commerce Program Category IV—The Physical Environment, which is composed of eight Program Subcategories containing a total of 20 Program Elements. This structure is related, to an extent, to the pre-ESSA organizational structure to provide for all the functions described in the previous section. The first six Subcategories represent ESSA's primary service missions, while the last two—Satellite Services and Research—have largely support roles. The final Subcategory H—Research includes most fundamental research. Applied or mission-oriented research and development, however, is included as an integral part of all the Program Subcategories.

ORGANIZATION

In order to maximize its services, ESSA is organized into five major line components which are assigned specific responsibilities for each of ESSA's eight Program Subcategories. These components are the Weather Bureau, the Coast and Geodetic Survey, the Environmental Data Service, the National Environmental Satellite Center, and the Institutes for Environmental Research.

Weather Bureau

The Weather Bureau is responsible for Subcategory

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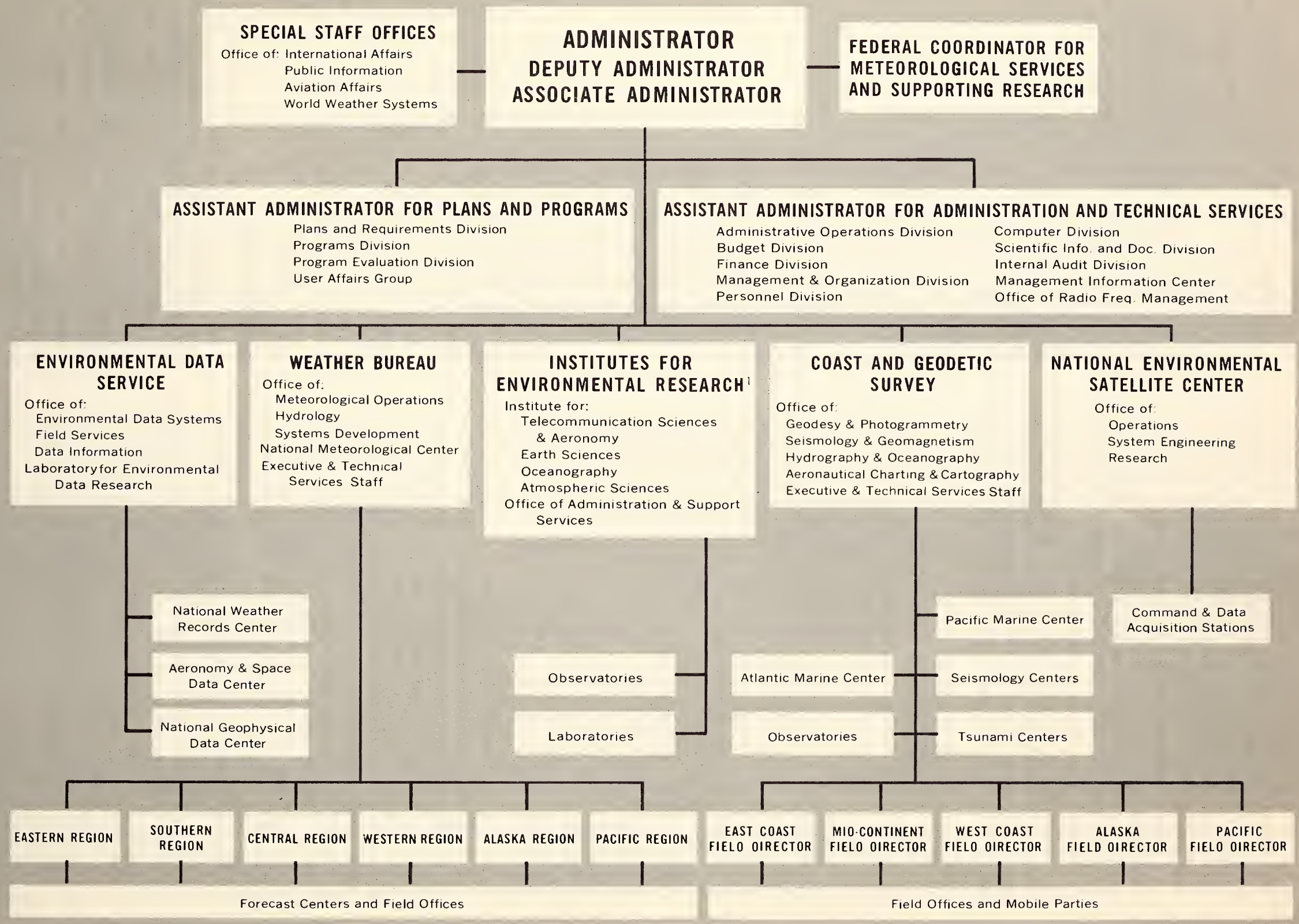


Chart 1.—ESSA Organization Chart, effective September 7, 1967.

[1] Effective November 9, 1967, the Institutes for Environmental Research were reorganized into the ESSA Research Laboratories.

A–Weather Forecasts and Warning Services, and Subcategory D–River and Flood Prediction and Warning Services. Within this framework, the Bureau, through a national network of some 300 offices, reports the weather of the United States and its possessions, records the climate of the United States, and issues warnings against tornadoes, hurricanes, floods, and other weather hazards. In addition to these basic services, the Weather Bureau develops and furnishes specialized weather services which support the needs of agricultural, aeronautical, maritime, space, and military operations. These services, themselves, are supported by a national network of surface and upper air observation stations, satellite systems, communications systems, and computers.

Coast and Geodetic Survey

The Coast and Geodetic Survey (C&GS) is responsible for Subcategory B–Description, Mapping, and Charting of the Earth, and Subcategory C–Oceanographic and Hydrographic Services. The Survey prepares aeronautical and nautical charts in order to promote safety and efficiency in air and marine navigation and conducts surveys to develop and maintain the precise geodetic control network that is essential to mapping and engineering projects. The Survey is active in photogrammetry and also operates a number of programs in geophysics, including satellite geodesy, gravity measurement, and determinations of the earth's size and shape. In a related activity, the Survey–through a system of geophysical observatories, mobile field parties, and a worldwide network of seismograph stations–monitors and reports earthquake activity, seismic sea waves in the Pacific, and variations in the earth's magnetic field. Finally, the Survey's oceanic operations include hydrographic surveys, marine gravity and magnetic surveys, and measurements of tides and currents. These activities are carried out by a 15-ship survey fleet also used by other ESSA components.

Environmental Data Service

EDS, responsible for Subcategory G–Environmental Data Services, maintains specialized data centers for the storage, retrieval, and dissemination of environmental data gathered on a global scale including geodetic, geomagnetic, seismological, and climatological information. Because of its broad range of data collections, EDS provides a single source of readily available environmental data to both specialized and general user groups. EDS is also active in the development of advanced automated storage and retrieval methods to improve its effectiveness.

National Environmental Satellite Center

NESC is responsible for Subcategory F–Satellite Services. It plans and operates environmental satellite systems, gathers and analyzes satellite data, and develops new methods of using satellites to obtain environmental data. At present, the Center operates the TIROS Operational Satellite (TOS) weather system, which employs ESSA (Environmental Survey Satellite) vehicles to monitor global cloud cover. As the ESSA series is improved and modified, sensors will be added to measure additional atmospheric characteristics, and to provide data in solar, ionospheric, oceanographic, and other geophysical phenomena.

Institutes for Environmental Research

The Institutes for Environmental Research are responsible for Subcategory H–Research and Subcategory E–Telecommunications and Space Services. The Institutes include the Institute for Earth Sciences (IES), the Institute for Oceanography (IO), the Institute for Atmospheric Sciences (IAS), and the Institute for Telecommunication Sciences and Aeronomy (ITSA). The Institutes, under a single Director, conduct and sponsor fundamental investigations needed to support ESSA's service programs, and, in general, develop new knowledge which man requires to cope with his physical environment. These activities are carried out within the Institutes themselves, and as contract and sponsored research.

In addition to its major line components, ESSA maintains a headquarters staff to provide centralized coordination of plans, programs, and technical-administrative activities. During this reporting period, the various components were directly responsible to the Administrator, who was assisted by a number of Staff Offices, both General and Special. The General Staff Offices consisted of the Office of the Assistant Administrator for Administration and Technical Services (AD), the Office of Science and Engineering (SE), and the Office of Planning and Program Evaluation (PL). These Offices advised the Administrator in matters relevant to the management of ESSA's components and performed many functions external to this management but related to ESSA activities. The Special Staff Offices included the Offices of: International Affairs (IA), Public Information (PI), User Affairs (UA), Aviation Affairs (AA), and World Weather Systems (WW). On September 7, 1967, in a realignment of interrelated functions, this organizational structure was modified, and the existing Offices of Planning and Program Evaluation, Science and Engineering, and User Affairs, were consolidated into one office under the direction of an Assistant Administrator for Plans and Programs. The overall organization of ESSA is shown in Chart 1.

FACILITIES AND RESOURCES

ESSA is a widespread organization with a staff of about 11,000 stationed throughout the world. In terms of personnel, ESSA now represents approximately 40 percent of total Department of Commerce strength.

ESSA operates a wide variety of facilities including weather observing and reporting stations, forecast centers, ocean vessel stations, the ESSA weather satellite system, and an extensive network of communications for meteorology–including an upper air network, a radar reporting network, a facsimile network, and a variety of surface networks, both in the United States and abroad, to transmit both general and special purpose weather information. In addition, ESSA mans and operates a fleet of oceanographic and hydrographic survey vessels,

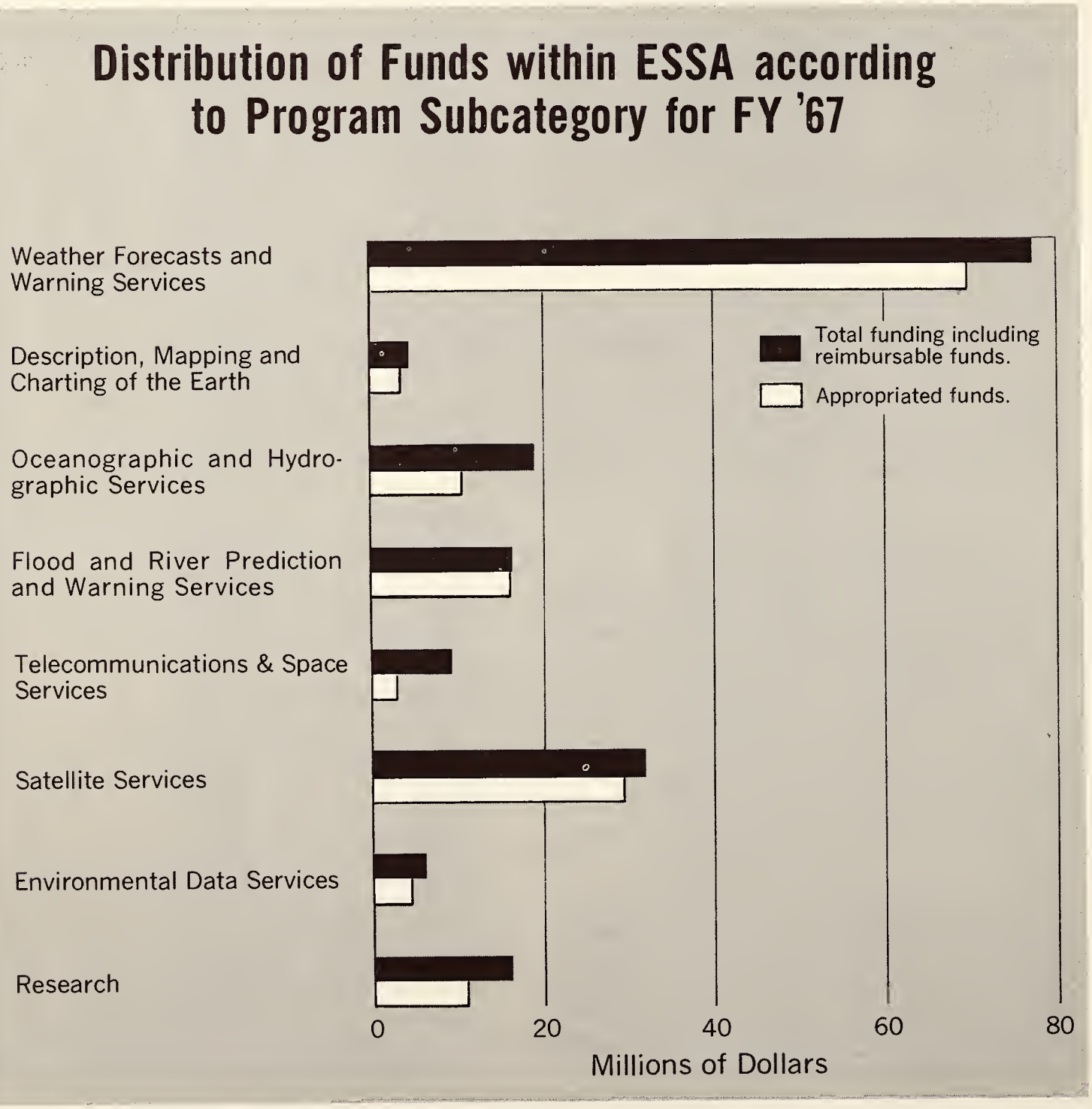
a small fleet of research aircraft, and a number of high-speed computer facilities. Either directly, or on a co-operative basis, ESSA collects magnetic and seismographic data on a global basis and operates the Worldwide Seismograph Network. For research on the upper atmosphere and telecommunications, ESSA owns and operates a variety of facilities, including the huge ionospheric research radar antenna at Jicamarca, Peru. These facilities, together with a number of others, will be described in greater detail in the subsequent chapters of this report.

In addition to its own facilities and personnel, ESSA makes extensive and increasing use of the talents and resources of outside organizations, through contracts and grants with universities, research institutions, and private industry.

In terms of financial resources, ESSA is roughly a $200 million per year organization, with funds distributed among the various Program Subcategories as shown in Table 1. As an organization primarily devoted to performing services for others, ESSA receives a substantial portion of its total funding from other agencies.

Table 1.

Distribution of Funds within ESSA according to Program Subcategory for FY '67



2 ESSA'S PRODUCTS AND SERVICES

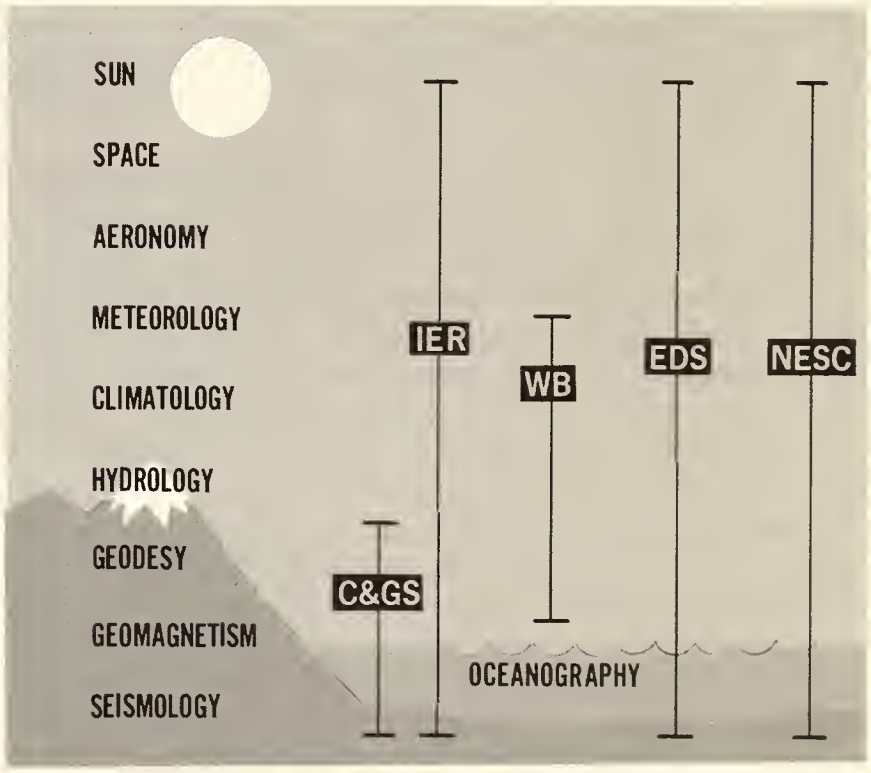
In directing its efforts, ESSA is guided by its assigned missions and an awareness of certain critical areas which require attention at a national level. ESSA is a service-oriented organization and its science and engineering programs reflect this. In some cases, certain services such as public weather forecasts are furnished directly to the user. In other instances, the service output is information for use by other organizations in carrying out their specific missions. An illustration in point would be the use of telecommunication results by the Department of Defense to improve military field communications.

ESSA pursues its major objectives in the following major areas:

- Description and understanding—these programs generally produce long-term or permanent products: reports, books, maps, and charts, etc.
- Prediction and warning—the products here are more ephemeral: forecasts and warnings through radio, TV, newspapers, etc.
- Engineering activities and services—the product here is action: a telecommunications system is designed, the weather is modified, etc.

DESCRIBING AND UNDERSTANDING MAN'S PHYSICAL ENVIRONMENT

ESSA's programs are closely related to one another in many ways. Consequently, describing and understanding the environment has for its primary purpose not only the provision of descriptive information *per se*, but also the provision of information useful for prediction and warning and engineering services as well. This portion of ESSA's program is thus defined to include those service missions and science and engineering programs whose immediate objective is description and understanding, regardless of how the product is eventually used. Programs in ESSA directed toward describing and understanding the environment embrace a variety of disciplines and regions, ranging from the solid earth and its fields, through the ocean and its solid boundaries, the boundary between land and air, the ocean and atmosphere, to the upper atmosphere and space. The scope and purpose of each area will be discussed in terms of regions of the environment, starting at the center of the earth, and moving outward to the near-space environment.



Relationship between environmental fields and services and ESSA components responsible for them.

The Solid Earth and Its Fields

The description of the solid earth and its fields embraces elements of the disciplines of geomagnetism, seismology, and geodesy. ESSA's descriptive programs in geomagnetism are conducted by the Coast and Geodetic Survey (C&GS). They include and support:

- The operation of geomagnetic observatories, performance of magnetic surveys, including repeat surveys; and the collection of geomagnetic information originating outside ESSA,

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- The compilation and production of charts indicating the distribution of strength and direction of the magnetic field,
- The processing, analysis, and dissemination of geomagnetic data,
- The furnishing of geomagnetic data and information required for air, marine, and space navigation,
- The provision of geomagnetic data and information required for land surveying, radio propagation condition forecasting,
- Support for forecasting of space radiation hazards,
- The determination of the solar-terrestrial relationship in various phenomena, and
- The study of the core, mantle, and crust of the earth.

ESSA's research program in geomagnetism is designed to achieve the capability for both prediction of the geomagnetic field with its variations in space and time and the achievement of a better understanding of the origin of these effects and their relationship to other phenomena of the physical environment. To attain these goals, ESSA performs research to improve instruments and systems, develops better methods and procedures for improved data collection and analysis, and investigates and studies interrelationships between the magnetic field and other parameters. The data for these studies are obtained from a worldwide network of magnetic observation stations as well as from local stations on land and sea, aircraft, and satellites.

ESSA's service program in the descriptive aspects of seismology is primarily concerned with teleseismology, or the acquisition of data from earthquakes at a distance by means of their resultant seismic waves transmitted through the earth. This program includes the operation of a worldwide standard seismograph network, the maintenance of a seismological data center, and the analysis and dissemination of data for engineering and scientific purposes.

ESSA's research program in seismology includes the development of new instruments and systems, the development of techniques to obtain more accurate information on earthquake hypocenters by improved knowledge of propagation mechanisms and the travel times of seismic waves, the study of the structure of the earth's core and mantle by seismic means, and the development of improved computational methods for data analysis.

Geodesy is the science that seeks to determine the exact position of points on the earth's surface, the figure and area of regions, the size and shape of the earth, and the variations of terrestrial gravity. ESSA's activities in geodesy are concerned with establishing and maintaining horizontal and vertical control points determined by means of surface, aerial, and satellite triangulation and photogrammetry. These programs involve astronomical observations, the measurement of gravity at various points on the earth's surface, and studies of earth movement. Additionally, ESSA is responsible for the publication and distribution of geodetic control data to engineers, surveyors, and the general public. This program provides accurate knowledge of locations and boundaries necessary for the conservation and development of natural resources; the needs of broad scientific and engineering projects, such as the microwave network for communication, interstate highway programs, petroleum exploration, transcontinental pipelines and transmission lines; and control requirements for urban development, and the national mapping program. This entire program is conditioned by the need to tie the map control grid of all nations together into a single world datum.

ESSA's research and development program in geodesy is concerned with the development of new techniques and instruments in the field of satellite and aerial triangulation, photogrammetry, long-range distance measurements, and gravity measurements including those made at sea.

The Ocean and Its Solid Boundaries

ESSA's programs related to the description and understanding of the ocean in relation to its solid boundaries fall within the fields of hydrography and marine geology and geophysics. Included also are studies of coastal tides and currents and interaction of the sea and land along coastlines and estuaries.

To date, tides, tidal currents, and the hydrography of coastal waters and estuaries remain perhaps the principal service mission of ESSA in the field of descriptive oceanography, although a growing effort in bathymetry (bottom topography) of the Continental Shelf and deep ocean areas is gradually modifying this emphasis.

ESSA's tide program consists of the operation of approximately 150 permanent or temporary tide gages by C&GS to monitor tides along the coasts of the United States and its possessions, and the production and analysis of the data collected. These data are used to provide the standards necessary to reduce soundings collected at various stages of tides to a common reference on nautical charts. These also form a basis for determining the tidal characteristics from which tide predictions are made. Also included is the maintenance of an internationally recognized catalog of tidal data. These data are in constant use in a wide assortment of scientific and technological problems. These include waste disposal, channel dredging and maintenance, land uplift and subsidence, worldwide sea-level change, water-supply problems, coastal engineering projects, geodetic level maps, and the determination of coastal boundaries.

In the field of tidal currents, ESSA service programs include the systematic collection of current observations and the reduction, analysis, interpretation, and the publication of these data. This activity results in a file of current data which is used in theoretical studies of estuarine dynamics in model experiments, in studies on the maintenance of coastal fisheries, and waste disposal analyses and investigations of sedimentation mechanics and channel maintenance. Based on current records, the characteristics of tidal currents are described, predicted, and published annually by C&GS.

These values are not only necessary for safe navigation of coastal waterways but are also part of the design criteria for coastal engineering projects.

Research in the area of tides and currents is concerned with improving knowledge of tidal propagation in both estuaries and the deep ocean in order to reduce uncertainties in tide predictions, estuarine dynamics, and nearshore ocean circulation.

ESSA's hydrographic programs are concerned with the various operations involved in the production of nautical charts and related publications required for the safety of marine navigation. They encompass such activities as hydrographic surveys (including the operations of ships), photogrammetric surveys and mapping, and the establishment of control points for these operations. They further involve investigations of hazards to navigation and location of aids for the navigator, including coast pilot information. The objectives of the hydrography program are to complete and maintain on an up-to-date basis the charting of the coastal waters including harbors and estuaries of the United States and its possessions. ESSA is also responsible for charting for recreational boating purposes lakes and reservoirs which are not in the areas of responsibility of other Federal agencies.

The large variety of published charts include harbor charts, small-craft charts, coast charts, general charts, sailing charts, and Loran charts. Approximately 5 million charts of all types were produced during the reporting period, of which about 50 percent were for civilian use and about 50 percent for military and naval use. In addition, the information given for charts is used to prepare the *Coast Pilot* which describes in narrative form certain types of data difficult to display on charts including information on the coasts, harbors, and waterways of the Nation.

Another important facet of ESSA's service program in hydrography is the operation by C&GS of a fleet of 15 oceangoing vessels for the collection of information on the Continental Shelf and the deep ocean basins. The goals of this program are related to determining the bottom topography or bathymetry of these ocean regions, the plotting of ocean currents for navigational purposes, the measurement of geophysical parameters such as marine gravity and geomagnetism at sea, and finally the provision of information of interest and value to the fishing industry.

ESSA's research programs relating to describing and understanding the ocean and its solid boundaries cover a broad range of activities, beginning with the interface of the ocean and the solid earth at the bottom of the sea (the benthic boundary). Studies span marine geology and geomagnetism, bathymetry, and the interaction of the sea with the land on shores, beaches, and in estuaries.

Aeronautical Charting

In addition to its responsibilities for the production and distribution of nautical charts for coastal waters, ESSA has similar responsibilities in the field of aeronautical charting and a general responsibility for the development of improved cartographic methods. ESSA's program in aeronautical charting involves all operations required for the production and maintenance of aeronautical charts and related publications needed for air navigation in the United States and its possessions. It includes field surveys and investigations and the compilation, reproduction, and distribution of the final product.

This program provides information needed for the safety of air navigation whether it is undertaken by visual aids or is performed by the use of instruments. It is intended to keep pace with the rapid advances made in aircraft design, capabilities, and resulting changes in methods of traffic control. Efforts are directed toward satisfying the needs of all sizes and types of aircraft. Additional key objectives are the meeting of the requirements of the Federal Aviation Administration in administering the Federal Airways System and the provision of charts needed by military aviation for operations over the United States and its possessions. Research in this area concentrates on the development of new and improved cartographic techniques. The program includes the development of new production techniques and concepts as well as development of new types of graphic display of information and studies for the improvement of present operating methods and systems used to provide nautical and aeronautical charts.

The Ocean and Atmosphere

Description and understanding of the earth's mantle of oceans and atmosphere is a key ESSA program since these elements of the environment are constantly undergoing change and continuously affect man's life. Disciplines involved in this area are physical oceanography, sea-air interaction studies, climatology, and atmospheric physics and chemistry. An important element of these disciplines is the search for improved mathematical modeling techniques of the fluid media and their interactions. Service programs in this area produce ocean survey reports, climatological surveys, and atmospheric data for a variety of purposes.

Ocean surveys consist of systematic observations of ocean phenomena, taken in conjunction with data required for hydrography and bathymetry. They include the reduction, analysis, and interpretation of these observations. The program includes the description of various properties within the water column such as temperature, salinity, chemical and nutrient content, and dissolved gases.

ESSA plays a major role in providing climatological services. These services involve the collection, analysis, and dissemination of climatological data including temperature, amount of rain and snowfall, barometric pressure, the relative humidity, wind velocity including winds aloft, solar radiation, and degree days. Data are collected by ESSA's Environmental Data Service (EDS) from approximately 1,000 land stations in the U.S.; 19 Automatic Meteorological Observing Stations (AMOS);

12 fixed ocean stations; and approximately 2,000 merchant vessels. In addition, daily measurements of temperature extremes and precipitation are made by volunteer observers at about 12,000 substations.

The data produced by these networks are analyzed and machine-processed at the National Weather Record Center and disseminated through regional and state climatologists and, through a variety of publications including: *Climatic Data, Weekly Weather and Crop Bulletin, Hourly Precipitation Data, Monthly Climatic Data for the World, Storm Data, Mariner's Weather Log,* etc.

This information has a number of economically significant uses. Users of special importance include: Agriculture for selection of crops, planting, and harvest time; the aviation industry for their choice of airport locations, direction of runways, and air route selection; marine interests for probabilities of hurricanes and other storms; and water management agencies for flood control data and irrigation design. Other applications include air pollution potential forecasts, preparation of data for weather prediction by computer means, guidance for military planners, and in the case of world climatological data, advice to travelers, airline operators, and U.S. companies wishing to market products abroad. These service programs are supported by a research and development effort covering the fields of statistical climatology, synoptic climatology, climatic change, bioclimatology (with emphasis on drought), severe storm climatology, three-dimensional global climatology, improved methods of data retrieval, and faster, higher density means of data processing and archiving.

The results of scientific research may themselves be significant products, being used later in other disciplines for the development of new or improved service capabilities. For example, the results of research in the physics and chemistry of the ocean and atmosphere are essential to the design and development of future prediction and warning systems and the perfection of means to modify the weather. Thus, ESSA has a substantial research mission in oceanography and the atmospheric sciences.

The Upper Atmosphere and Space

In the near future, the upper atmosphere will be the environment for supersonic transport aircraft. Even today, the upper atmosphere and the space in the near vicinity of the earth are the environment for manned space vehicles and instrumented, unmanned vehicles. In addition, the upper atmosphere contains varying numbers of charged particles which have an important effect on telecommunications. Thus, there exists a critical, continuing necessity for description of this portion of the environment. The development of information necessary for the execution of this program is a principal service product of ESSA's program in this area, and this program is conducted by the Institute for Telecommunication Sciences and Aeronomy (ITSA).

ESSA's research effort in aeronomy—the science dealing with description of the upper atmosphere and near-space—includes the study of the upper and lower ionosphere by both direct (satellite) and indirect (radar) means, simulation of the upper atmosphere in the laboratory to study atmospheric composition and processes, and the study of those variations in the earth's magnetic field produced by ionospheric fluctuations and solar disturbances.

ENVIRONMENTAL PREDICTION AND WARNING

Perhaps the most dramatic of ESSA's current missions is the prediction of the behavior of the environment and the issuance of warnings of environmental hazards. A large percentage of ESSA's resources is devoted to providing services and solving problems related to prediction and warning, including indirectly a number of research areas previously described. ESSA's goals range from finding a means to predict destructive earthquakes and tsunamis (seismic sea waves) through weather forecasting to warnings of potentially harmful disturbances in the near-space environment.

Earthquakes and Tsunamis

Although certain regions of the United States are better known than others for damaging earthquakes—i.e., California and Alaska—there are few States in the union which have not had at least one earthquake severe enough to cause some damage. The same is true for almost every region of the earth. The Prince William Sound, Alaska, earthquake in March 1964 demonstrated a need for improved understanding of earthquake mechanisms, both to permit the prediction of these events and to provide better guidance for the design of earthquake-resistant structures. Studies by the Institute for Earth Sciences (IES) and C&GS seek to determine the physical mechanisms by which earthquakes take place. These studies include fault instrumentation, after-shock studies, tilt meter observations, geological and geophysical field surveys, geodetic surveys, strain measurements, and geomagnetic measurements.

A particularly important service function of ESSA is the operation by C&GS of the National Tsunami Warning Center for the Pacific Ocean area. This service was inaugurated after the destructive tsunami of April 1, 1946, which took 173 lives and cost $25,000,000 in property damage in Hawaii alone. The Center at Honolulu evaluates the tsunami potential of earthquakes reported in the area and issues alerts and warnings where indicated to the various countries bordering on the Pacific that participate in the service.

The problem of prediction is particularly difficult because not all underwater earthquakes produce tsunamis, and the runup is critically affected by bottom topography and wave amplitude. Consequently tsunami research is primarily directed toward improved prediction methods consisting of mathematical prediction models continually modified by tide gage data inputs.

Ocean and Atmosphere Prediction and Warning

Both in terms of resources and assigned personnel, the Weather Bureau is the largest single activity of ESSA. Its personnel are found at approximately 400 facilities within the United States, at 14 overseas stations, and on 21 ships at sea. Altogether, the Bureau has some 5,000 full-time employees working in meteorological and hydrological operations. In 1 year, approximately 3.5 million observations are taken and 1.9 million forecasts and warnings issued.

The ESSA service program best known to most people is the public weather service of the Weather Bureau. This service through its local offices provides weather information, forecasts, and warnings, which are distributed in cooperation with news media. These products also serve as a starting point for most interpretive and specialized forecast services including the many detailed services provided by industrial and consulting meteorologists. For long-range weather planning needs, certain climatological information is available at each local Weather Bureau office. Figure 1 shows the location of the approximately 235 Weather Bureau offices in the United States and Puerto Rico.

The Agricultural Weather Service was established to supply meteorological services including forecasts, warnings, and advice of particular use to the agricultural community. This Service currently serves all or part of 20 States and plans call for similar services to be extended to all sections of the country if funds permit. Services include:

- Detailed weather forecasts beneficial to farming operations. In certain locations, special emphasis is placed on the prediction of frost;
- Extension and advisory services to acquaint farmers with the potential benefits and profits to be derived from weather information; and
- A communication system designed to make information services readily available through radio and TV to both agricultural interests and the general community.

Figure 1. Weather Bureau stations, conterminous United States and Puerto Rico.

In order to furnish weather information necessary for safe and efficient flight operation at airport terminals and along flight routes, the Weather Bureau maintains an extensive Aviation Weather Service. This Service provides forecasts and briefings for international and domestic flight operations in that region extending from the surface to operational levels of civil jet aircraft. The Aviation Safety and Quality Control Service evaluates, forecasts, and plots weather briefing effectiveness; and also provides technical support for aircraft accident investigations, safety enforcement proceedings, and civil litigation.

Service to international aviation is provided for a large portion of the Northern Hemisphere in accordance with the procedures of the International Civil Aviation Organization (ICAO). This service is rendered primarily by five Main Meteorological Offices (MMO) and the Analysis and Forecast Division of the National Meteorological Center. In addition, a network of 29 meteorological offices serves international aviation by providing briefings and flight documentation services.

The Fire Weather Service provides specialized forecast, advisory, and warning services to Federal, State, and private fire-control and forest-management groups through one or more fire-weather meteorologists who are stationed at 40 Weather Bureau offices and by the use of mobile units when forest fires reach a predetermined size. These forecasts are made twice daily in most areas during the forest fire season and are also issued more frequently if required during a fire.

The Marine Weather Service of the Weather Bureau supplies weather and sea state forecasts, warnings, and data essential to the conduct of effective and safe marine operation.

The National Hurricane Warning Service, which operates through several Centers, is responsible for warning the public of hurricanes and other tropical storms. The Centers furnish basic hurricane advisories and bulletins coordinated for prognosticated hurricane positions, tropical weather outlook, and post-storm reports. The Centers conduct research and development for improved means of detecting and predicting hurricanes as well as on the tropical weather processes that lead to their formation. Similarly, the Severe Local Storms Forecast Center furnishes warnings of tornadoes and severe local storms. Other more highly specialized program areas of the Weather Bureau include: Support of the Nation's space programs, both missile and space flight; studies of polar regions; and special studies with regard to the proposed Interocean Canal Project.

The Basic Weather Service Program supports the public weather service, and all the Weather Bureau's specialized weather services and warnings by providing the necessary meteorological information and products. This program is concerned with data acquisition, communication, analysis, and dissemination which are common to the other programs. The basic meteorological organization to carry out this program is composed of three echelons:

- The National Meteorological Center (NMC), the National Severe Storms Forecast Center (NSSFC), the National Hurricane Center (NHC), and the Tropical Analysis Center (TAC) constitute the top echelon.
- The area forecast centers (22 in the conterminous United States plus one each in Anchorage, Honolulu, and San Juan) are the key elements of the field forecasting operation. These centers are responsible for warnings and forecasts for States, or large portions of States. Area or statewide forecasts cover about 48 hours and are issued four times daily. They are also issued to the public in critical weather situations. This echelon provides the main field forecast support for the marine and aviation programs and guidance for the agricultural and fire-weather programs.
- The zone and local forecast offices represent the third echelon of the system. Zone and local forecasts are adaptations of the State forecasts. They are issued to meet local requirements but do not extend beyond the period covered by the official State forecasts. This echelon has important warning distribution responsibilities and is usually the location of the fire-weather and agricultural forecast offices.

NMC provides basic weather analyses and forecast guidance for use by field offices. It also provides an increasing number of meteorological byproducts such as wind forecasts for aviation and precipitation forecasts for hydrology and public services.

The centralized preparation of data analyses and forecasts is designed to eliminate most requirements for hand charting and independent meteorological analysis at field forecast offices. The computer facility plays a significant role at NMC where the principal objective is the promotion of increased use of numerical methods in preparing both short-range and extended-range forecasts.

In the course of one day, NMC receives: 12,000 synoptic and 25,000 hourly surface aviation reports, 1,400 synoptic ship reports, 1,500 upper atmospheric and winds aloft reports, 500 aircraft pilot reports, and 160 global satellite cloud photographs. These data receive wide distribution. Each day, NMC makes nearly 600 facsimile and 200 teletypewriter transmissions to field offices.

The National Environmental Satellite Center (NESC), another major component of ESSA, is a major contributor to the fund of data and analysis upon which forecasts are based. The successful launches of the environmental survey satellites ESSA I and II in February 1966 and subsequent launches of ESSA III, IV, and V established the world's first operational weather satellite system. These satellites provide regular and reliable daily weather observation of the entire globe for central analysis, and local area photographs for more than 200 ground stations scattered around the world. This is the first time that such information has been obtainable on a global, synoptic basis (i.e., from a broad area nearly simultaneously)

and permits early identification of locations of weather over the oceans which may affect the shoreline, as well as providing data for global weather studies. The Center conducts research on improved utilization of satellite data, new types of environmental satellite systems, and development of improved instrumentation.

River and Flood Prediction and Warning

An important service mission of ESSA is the forecasting of river levels and the issue of necessary flood warnings; this is carried out through the Office of Hydrology of the Weather Bureau. Continuous forecasts of high, low, and intermediate flows are increasingly important for water supply, flood control, pollution abatement, navigation, and efficient reservoir operations, as well as many other purposes. The Office of Hydrology conducts research in river forecasting, evaporation, rate of heating, snow melting processes, precipitation frequency, and the use of satellite data for these hydrologic purposes.

Telecommunications Prediction

The effective use of radio frequencies for telecommunications, particularly over great distances, depends heavily on ionospheric and atmospheric conditions. A vital service mission, conducted through ESSA's Institute for Telecommunication Sciences and Aeronomy (ITSA) is the regular distribution of forecasts of usable frequencies in various portions of the world as a function of both the time of day and the day of the year. This service is essential for both commercial long-distance communication and military communications. ITSA conducts research on the effects of ionospheric and atmospheric variables at various frequencies, and in improved means for their prediction.

Space Disturbance Prediction and Warning

ITSA's Space Disturbance Forecast Center maintains a 24-hour surveillance of activities on the surface of the sun. These activities are in the form of fluctuations in the magnetic field, ionizing radiation, and high-energy particles. They produce reactions which may be highly destructive to communications and can be extremely dangerous to astronauts in the near-space environment.

ENVIRONMENTAL ENGINEERING SERVICES AND ACTIVITIES

The operating policies of ESSA emphasize the description, understanding, and prediction of the physical environment, but there is also considerable activity related to the application of the knowledge gained to the solution of specific problems. Among the major activities in these areas are engineering seismology, ocean engineering, environmental pollution abatement, telecommunication engineering, and weather modification.

Engineering Seismology

ESSA uses seismologic data to guide engineers in the design and location of structures in earthquake-prone regions and for the detection of underground nuclear blasts.

The C&GS service programs in engineering seismology produce information on earthquake mechanisms for the guidance of structural designers in various regions. Criteria for structural design are developed jointly with the National Bureau of Standards. C&GS then performs cost benefit analyses to determine the economic factors relating to the use of these criteria. Research in support of this program includes regional studies, strong-motion studies, and rock and soil mechanics.

While there is no program in ESSA designed specifically to detect underground nuclear blasts, this objective is achieved through the operation of seismological networks primarily designed for other purposes. Similarly, research in support of this objective also supports teleseismology.

Ocean Engineering

Many ESSA programs, such as bottom sampling, bathymetric mapping, and physical oceanography, contribute important ocean engineering data. The development of ships and buoys constitutes a relevant application of ocean engineering techniques. However, there are several ESSA activities which fall directly in the engineering field. Included are the dissemination of information on the bearing strength of bottom sediment, and the publication of studies of wave climatology for the guidance of ship designers and operators. Research in ocean engineering covers improved techniques for data acquisition, equipment development, and climatological studies.

Environmental Pollution

Although plans call for expansion of this program in both scope and size, ESSA already performs essential services related to the problem of environmental pollution and its abatement. These include air pollution potential advisories, now prepared for a number of urban areas on a routine basis; river flow forecasts by the Weather Bureau; estuarine flushing predictions by C&GS; and a number of special services, such as the prediction of trajectories for radioactive fallout. Research in environmental pollution covers estuarine studies, atmospheric radioactivity, trajectories, pollution chemistry, and certain aspects of air turbulence.

Telecommunications Engineering

The earth's surface and atmosphere have many effects on electromagnetic waves. The goal of ITSA is to predict these effects quantitatively, spatially, and temporally, in order that the Nation may realize the maximum possible return from its expenditure on electromagnetic telecommunications systems; and in order that the electromagnetic spectrum, an essential natural resource, be used with maximum effectiveness. ITSA's task as the central Federal agency for propagation research and services, is to obtain and disseminate information on the distortions and attenuations experienced by these waves as they travel from transmitter to receiver to provide design criteria for telecommunications systems.

To meet this mission, ITSA must work at all relevant

communications frequencies (from about 10^3 to about 10^{15} Hz, or wave lengths from about 10-millionths of an inch to about 200 miles); at all relevant ranges; at all heights (including below the surface of the earth or oceans and up to satellite altitudes); and in all locations and climates (from pole to pole and in space); and in support of all significant uses of telecommunications (such as defense, aviation, navigation, public safety, communications, entertainment, and space research). Ionospheric and tropospheric telecommunications are the two major categories of research performed in support of this service mission. Because of the nature of ionospheric propagation, the first category deals essentially with the frequency range from 1×10^3 to about 10^7 Hz. The balance of the spectrum lies in the second category.

Research in ionospheric propagation includes all radio propagation factors affecting the design and use of radio systems for long-distance radio communications, navigation, timing, detection, and positioning. Studies of ionospheric ground wave and line-of-sight radio paths are made to define their limitations in capacity as a transmission medium. Standards and methods of measurements for radio systems are developed in order to fulfill the needs of Federal agencies and industry. Research in support of tropospheric communications engineering covers spectrum utilization, studies of the electromagnetic interference environment, millimeter wave propagation, and infrared and optical propagation.

Modification and Control of the Environment

Studies of means to modify and control the environment are still in an early stage, and as a result, there does not yet exist a service program in this area, other than the development of information and knowledge through research. Although eventually other elements of the environment will be investigated, efforts so far have been limited to two fields, one a very limited study of modification of the ionosphere to affect telecommunications, and the other, ESSA major objective areas related to weather modification.

SUPPORTING SERVICES AND FACILITIES

The essential unity of the environmental sciences is most evident in the common use of instruments, equipment, and facilities. While each area has needs peculiar to itself, there is considerable opportunity for common and even simultaneous use of platforms, sensors, communications, data processing, and archiving facilities.

The development and operation of these facilities and equipment are in some cases a service function of ESSA performed both in support of its own operations and in various fields, and in support of other agencies as well. The following are some of the programs in this category.

Platforms and Stations

Platforms of a wide variety are developed and operated by ESSA for both operational and research data acquisition. These include a large number of general and special purpose laboratories and test sites, an underwater stable platform for measuring geophysical parameters at sea, buoys, a fleet of oceangoing vessels, a small fleet of instrumented research aircraft, balloons, and environmental rockets and satellites. Research and development is performed to adapt sensors to platforms, improve data acquisition to solve engineering problems, and to improve or innovate the facilities themselves.

Sensors

Sensors and other instruments are developed and improved in connection with almost every area of environmental science and service. However, two programs of ESSA have the broad objectives of contributing to a number of different fields: The development of space-qualified sensors for satellite application at NESC, and an investigation of the use of electromagnetic radiation as a remote sensing device for environmental science at ITSA.

Communications

The Weather Bureau has an extensive network of communications for the transmission of raw data, forecasts, and warnings. To an increasing extent, this network is being used for transmission of other types of environmental information, particularly warnings in connection with the NADWARN program. Because future plans call for the real-time communication of a much larger volume of data in a number of environmental areas, studies are being made of future requirements and the means to meet them.

Data Processing

ESSA already has an enormous amount of data to process each day and this amount will grow. Virtually all programs routinely use computer processing either by means of specifically allocated facilities or through the sharing of time on other computers. ESSA's Computer Division monitors computer acquisition and usage to obtain maximum utilization of facilities compatible with efficient operation. Studies of future needs and the means to meet them are underway.

Archiving

EDS, in addition to performing climatological services and research, has a major responsibility for the archiving of environmental data in a number of different fields. The Service maintains specialized data centers for geodetic, geomagnetic, seismological, climatological, and other geophysical information. It provides a single source of environmental data to specialized and general user groups. Research and development is performed in advanced data storage and retrieval methods in support of these services.

Ionospheric and space disturbance data are archived at ITSA under the direction of EDS. In addition, ESSA contributes to the support of the National Oceanographic Data Center.

3 SELECTED HIGHLIGHTS

During its first 2 years of operation, ESSA established a management system which integrated the functions and missions of separate agencies in the Department of Commerce involved in the environmental sciences. This unified organizational structure has enabled ESSA to begin an integrated, balanced, and coordinated program of research and development and services. It is expected that this approach will yield improved description, prediction, and gradually increasing, though limited, control of the physical environment.

ORGANIZATION AND MANAGEMENT

The administrative organization and integration of ESSA's components are significant achievements of this period. The successful completion of the necessary organizational changes required the sorting out and harmonizing of three sets of policies, procedures, and managerial structures.

The establishment of the Institutes for Environmental Research was a milestone in the evolution of the concept of the essential unity of environmental science. By the end of FY 66, the Weather Bureau's Office of Meteorological Research had emerged as the Institute for Atmospheric Sciences; the Research Division of the Coast and Geodetic Survey had evolved into the Institute for Earth Sciences and the Institute for Oceanography; and finally the Central Radio Propagation Laboratory and the Geoacoustics Group of the National Bureau of Standards had become the Institute for Telecommunication Sciences and Aeronomy. The headquarters of the Institutes, located at Boulder, Colo., is responsible for planning and supervision of basic and applied research needed to support ESSA's missions both in the present and the future.

ESSA also established, during this reporting period, an Office of Science and Engineering to monitor the interface between the basic research programs of the Institutes and development activities of the service bureaus. This group also coordinated ESSA-wide efforts designed to attain selected major program objectives, and it represented ESSA on various boards and committees within as well as outside the Federal Government.

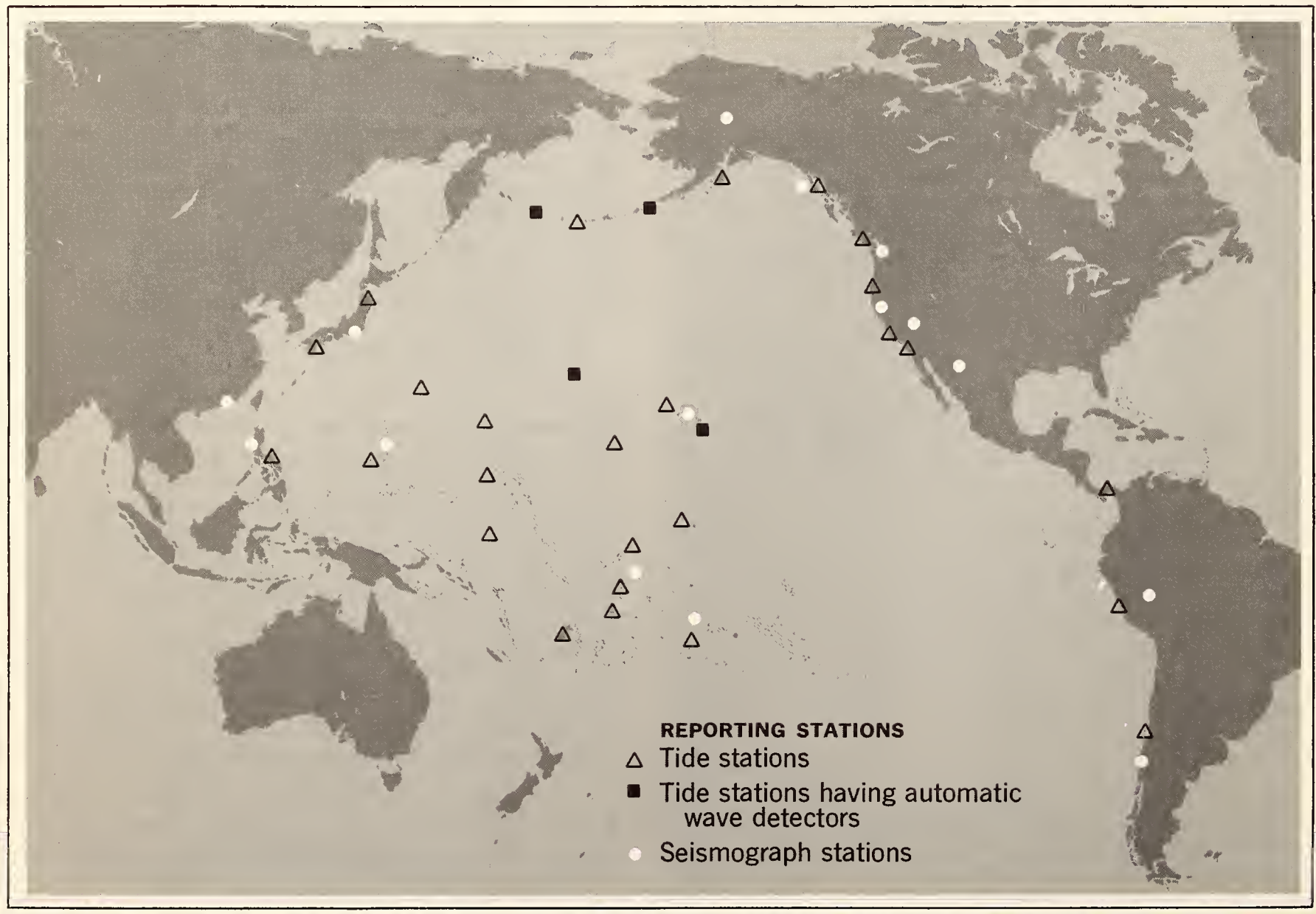
SERVICE PROGRAMS

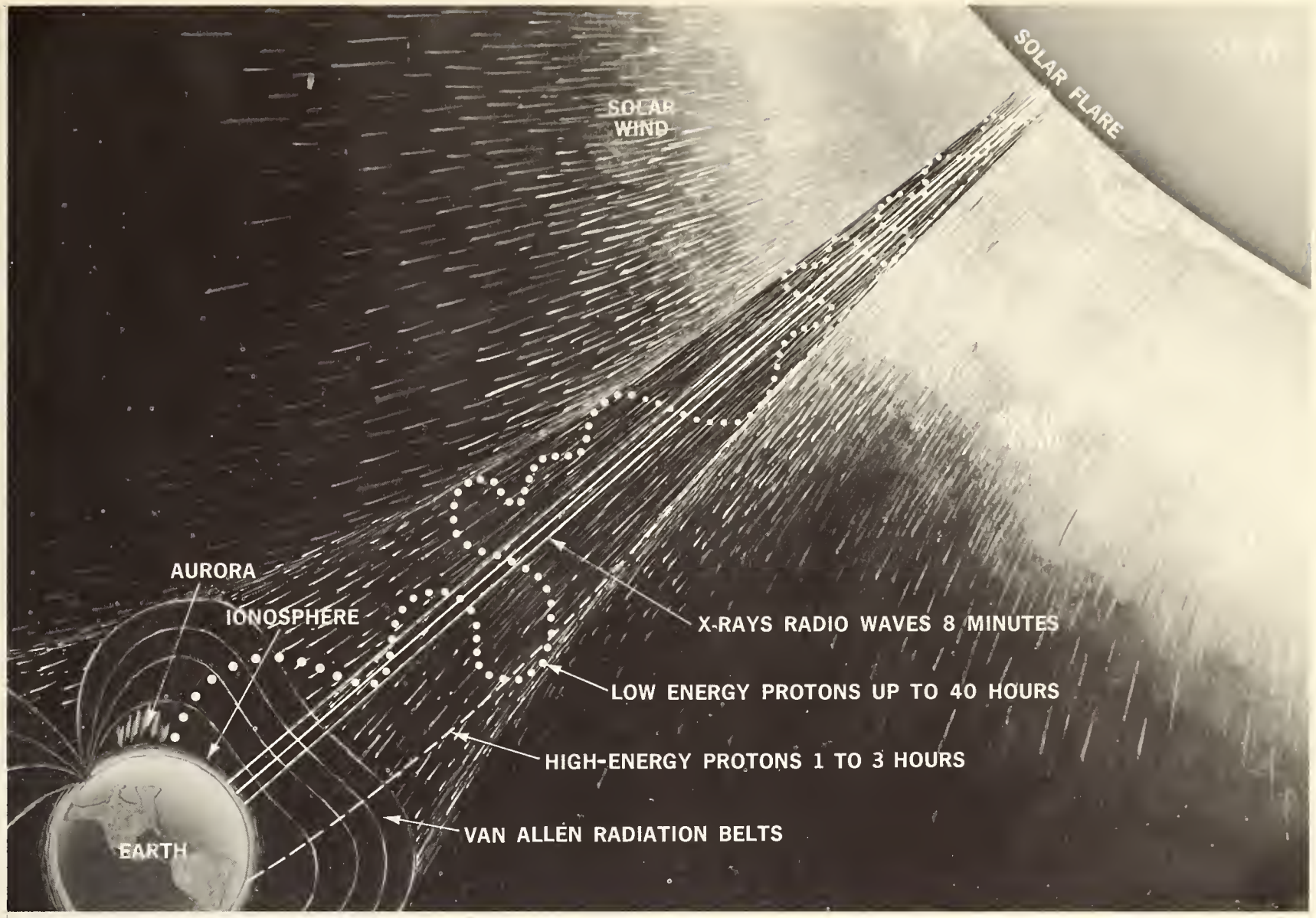
During its brief existence, ESSA has made significant progress in its service programs. For example, an Interagency Disaster Warning Survey Group was established following the Palm Sunday tornado disaster in the Midwest on April 11, 1965. Under ESSA leadership, this group completed its study during this reporting period, and prepared a plan for a nationwide Natural Disaster Warning System (NADWARN) which would use existing technology and facilities to provide more rapid means for warning the public of impending natural disasters. The NADWARN System, which will eventually furnish warnings of space disturbances, weather hazards, floods, seismic sea waves (tsunamis), earthquakes, and upper atmospheric hazards, was established in FY 67.

The tsunami warning system, one of the key elements of the NADWARN System, was established during this reporting period at Honolulu, Hawaii. A network of seismograph and tide stations feeds information on a real-time basis to the National Tsunami Warning Center. This information is analyzed by computers located in the Center which then predict arrival times for the various areas bordering the Pacific. The tsunami warning system currently transmits information to a number of countries and is being improved as rapidly as possible. For example, research performed by an ESSA scientist working at the Joint Tsunami Research Effort at the University of Hawaii has led to a new computer program which predicts the convergence and divergence of energy from a tsunami at any point in the Pacific Ocean from an origin at any point in the Pacific.

In an analogous effort, ESSA established a National Earthquake Information Center on August 15, 1966, located at the Coast and Geodetic Survey (C&GS) headquarters in Rockville, Md. This Center functions as a

Tsunami Warning System





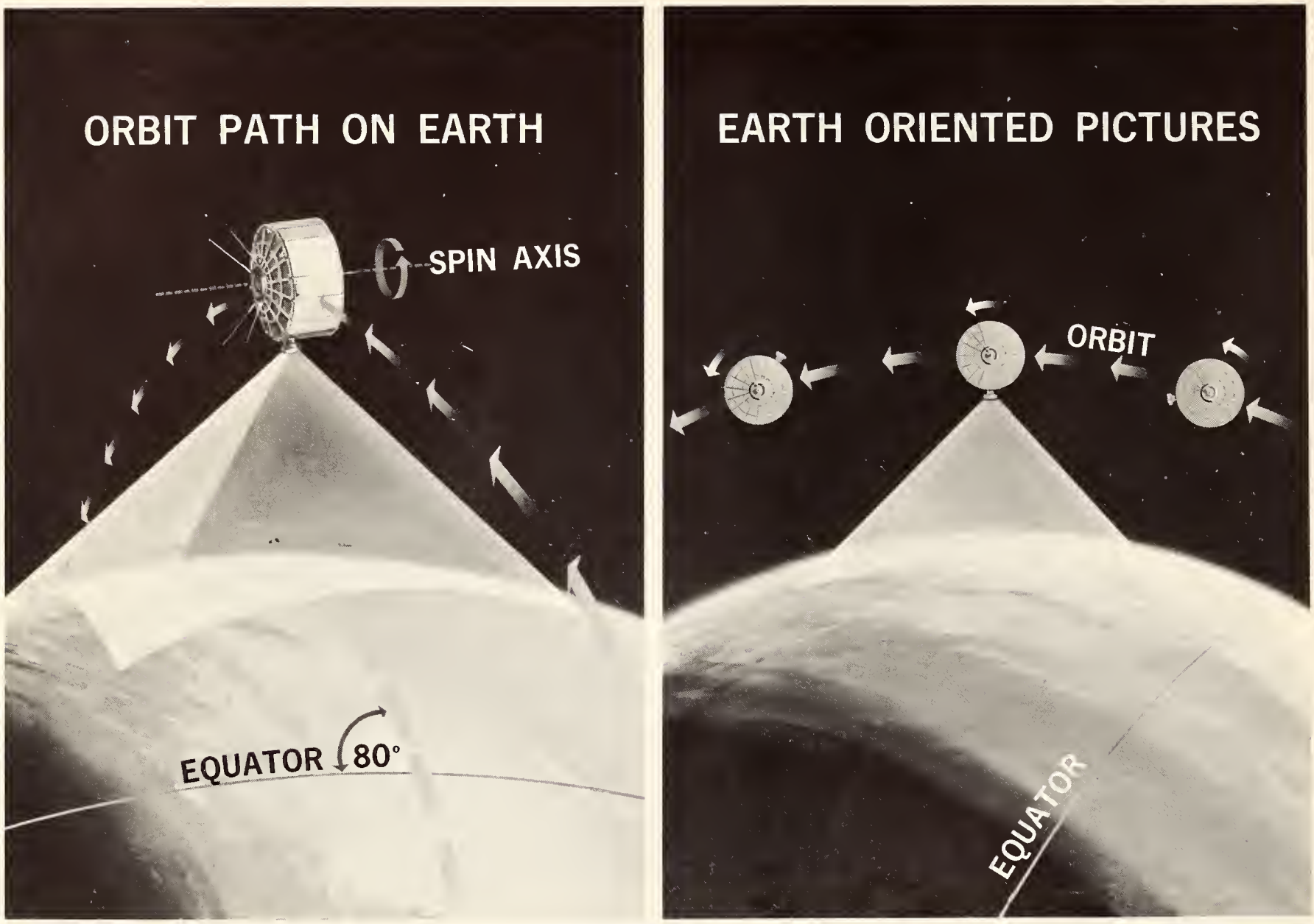
Artist's conception of the manifestations of a solar flare. Emissions from the sun disrupt the magnetosphere and ionosphere, interfering with long-distance communications and delicate satellite electronic operations. Solar flares, which may be hazardous to man beyond the protective covering of the atmosphere, are investigated and forecasted by the Space Disturbances Laboratory.

focal point for the dissemination of seismic information for both the general public as well as specialized audiences, through various media, such as its monthly *Earthquake Information Bulletin*, which was begun in March 1967.

The first new service to result from the Center is an Earthquake Early Reporting System which provides accurate and rapid hypocenter locations for magnitude values over six on the Richter Scale. The range of the network is presently limited to that portion of the Western Hemisphere centering around the United States but will be expanded to include reports from selected foreign observatories.

A highly significant aspect of the general area of warning is the detection and prediction of solar flares. In September 1965, a new Space Disturbances Monitoring Facility became operational near Anchorage, Alaska. At this facility, various geophysical effects related to changes in the earth's radiation environment are monitored by ground-based sensors. A new Space Disturbance Forecast Center was established at the Institute for Telecommunication Sciences and Aeronomy (ITSA) in Boulder, Colo. Daily forecasts of solar flare occurrence probabilities, solar proton event probabilities, and the prediction of the general level of several important solar-geophysical indices are disseminated to a growing number of recipients. Special solar activity forecasts are also prepared in connection with a number of NASA space programs.

In addition to its programs in natural hazard warning, ITSA plays a major role in the application of telecommunications engineering to other national problems. For example, ITSA's Tropospheric Telecommunications Laboratory designed in less than a year a nationwide communications network for the FBI's National Crime Information Center in Washington, D.C. This system, using mostly common carrier microwave links, provides for the rapid transmission of information between the Center and State and metropolitan law enforcement agencies. ITSA is even at present working with the FBI to explore the application of new technology to the needs of the 1970's.



The TIROS Wheel Satellite, the basic spacecraft for the TOS System, photographs 4 million square miles with each rotation about its axis and covers the entire earth once each 24 hours.

One of the most important events within the past 2 fiscal years was the launching by NASA for ESSA of the world's first operational weather satellite system in February 1966 and the subsequent initiation of routine satellite collection of meteorological data. The TOS System (TIROS Operational Satellite System), of which ESSA I and II were the first vehicles to be launched, obtains cloud photographs on a global basis, which are then transmitted to ground stations. The TOS System has been expanded with the launching of ESSA III on October 2, 1966, which replaced ESSA I; ESSA IV on January 24, 1967, which supplements ESSA II; and, ESSA V on April 20, 1967, which supplements ESSA III.

The system operates in the following manner: ESSA I, III, and V, using Advanced Vidicon Camera Systems (AVCS) store pictures for readout to two Command and Data Acquisition Stations and relay to the National Environmental Satellite Center (NESC). The pictures and data are processed at the Center and furnished to the National Meteorological Center (NMC) for incorporation into operational analyses for worldwide dissemination. ESSA II, however, takes and transmits local area pictures to suitably equipped ground stations within 1,800 nautical miles of the satellites. (ESSA IV is not at maximum operating capacity.) This latter system, called APT (Automatic Picture Transmission), has had considerable international impact since a nation, corporation, or even an individual can, for only a few thousand dollars, purchase the necessary equipment to obtain twice daily pictures of local cloud cover. ESSA II presently transmits to some 200 APT ground stations.

An important innovation in the Weather Bureau's service program was the introduction of probability forecasting for the general public. This type of forecasting provides quantitative information regarding the degree of uncertainty in weather events. These forecasts are based to a large extent upon a statistical analysis of empirical evidence. In other words, a forecast of a 60-percent probability of precipitation means that in 60 percent of the cases when a similar atmospheric weather pattern existed in the past, precipitation resulted. This system is beginning to enjoy wide public acceptance since it

permits better planning, especially by weather-sensitive businesses which can apply these percentages to their production schedule formulas and derive profit versus loss ratios.

Finally, ESSA's Air Pollution Potential (APP) advisory program became operational on July 1, 1966. Tabular and graphical output were used at first to support the Weather Bureau's forecast center at Cincinnati. During the year, the final preparation of guidance forecast charts for national distribution was taken over by NMC.

RESEARCH AND DEVELOPMENT

Two major new research facilities were added to ESSA's complement with the commissioning of the Oceanographic Survey Ships, *Oceanographer* and *Discoverer*. These vessels, designed for deep ocean survey, have fully equipped environmental science laboratories; closed circuit television; equipment for automatically logging data from oceanographic, meteorological, and ionospheric sensors; and on-board computers for preliminary data analysis. Both vessels were constructed as part of a coordinated 10-year oceanographic survey program developed by the Interagency Committee on Oceanography of the Federal Council for Science and Technology.

ESSA also made significant progress in seismology during this period. Construction was initiated of a major research facility at Stone Canyon, near Hollister, Calif., for the interdisciplinary study of earthquake mechanisms along the San Andreas Fault. Measurements will be made in the vicinity of the fault to determine significant correlations that might offer an approach to practical earthquake prediction.

In another contribution to seismology, ESSA's Albuquerque Seismological Center developed and fabricated seismograph systems to record the relative amplitudes of seismic waves in various types of geologic formations. The information obtained is used to estimate the effect of earthquakes on foundation materials. This type of information is extremely important to architects and structural engineers in earthquake-prone areas. In fact, the results of a recent study of California school structures indicated that less than 1 percent of the structures built according to design criteria based on these data were damaged by earthquakes, compared to 67 percent damage of structures not built according to these criteria, under the same earthquake conditions.

ESSA also tested a new technique of using a laser beam with a Geodimeter to extend the distance at which wide triangulation can be made of the surface of the earth. This device has resulted in considerable savings by enabling the C&GS to reduce the number of observations needed to establish accurate geodetic control, particularly in the vicinity of densely populated areas having poor visibility because of atmospheric pollution.

In an effort to collect oceanographic data on a continuous basis, ESSA developed a system called ODESSA using buoy-supported instruments to measure temperature, salinity, current speed and direction, and depth of observations. This system can make measurements of these parameters at eight different depths simultaneously, either recording data automatically on magnetic tape for later retrieval, or telemetering it directly to shore stations on demand. Prototypes of the ODESSA system are now being field tested with their operational deployment over the Continental Shelf scheduled for early FY 68.

Major progress was also made in weather satellite instrumentation. NESC in cooperation with NASA sponsored the development of a new spin-scan camera which was flown successfully on NASA's ATS–1 synchronous satellite. This camera took photographs at 20-minute intervals of cloud pattern evolution in the Pacific Ocean area. There were equally significant advances in the interpretation and use of satellite photographic data. A method was developed to estimate the winds in hurricanes and tropical storms which has proved accurate, in most cases, to within 25 miles per hour.

Any improvement in weather forecasting requires not only global data, but also accurate mathematical models of the atmosphere for the conversion of the data to forecasts and warnings. A major problem in this type of modeling is the complexity of the interactions involved and the difficulty of obtaining solutions that do not diverge with time due to nonlinearities in the original or "primitive" equations. Previously, it has been necessary to modify these equations, using simplifying assumptions which made stable solutions possible, but also reduced their value. However, during the reporting period, NMC was able to obtain stable numerical solutions to these equations, which will permit more accurate machine forecasts for up to 6 days in advance. Ultimately, with these equations, it should be possible to obtain accurate com-

Measuring 8-mile line at Beltsville, Md., with laser Geodimeter.

puter prediction of the weather for up to 2 weeks in advance if adequate data are available.

Along similar lines, the Institute for Oceanography developed and successfully tested a mathematical model of the interaction between the air and sea which produces "storm surge" (unusually high, storm-driven tides). This model is important for timely and accurate warnings of unusually high or low tides, and can be of great value to coastal communities by saving both lives and property. It is already in use by the Weather Bureau at Atlantic City and will be extended to other coastal areas in the near future.

The first statistically significant evidence that tropical cumulus clouds can be modified by seeding was obtained during FY 66 in the Caribbean by the Atmospheric Physics and Chemistry Laboratory. These results are critical for both future efforts to moderate the force of hurricanes and in attempts to affect rainfall along the coasts of the United States. The general validity of the provisional physical model used to predict cloud growth and behavior has been established.

Tropical cloudiness and rainfall have been shown to be closely related to surface pressure variations having important diurnal and semi-diurnal components associated with the solar and lunar tides. Further evidence has been found that the quasi-biennial oscillation is, at least in part, a tidal phenomenon and that there is an atmospheric response to the tidal perturbations in terms of a latitudinal adjustment of pressure.

In addition to the evaluation of successful 1965–66 experiments, development of pyrotechnic seeding agents for release from aircraft was undertaken, and, jointly with the National Hurricane Research Laboratory, the design of a field research program for a study of the natural ice crystal development in maritime cumulus clouds was begun.

The work in these areas forms the basis for the design of cumulus seeding experiments in Florida during the spring of 1968. These experiments will be designed to study the development of cumulus clouds after release of heat of fusion caused by seeding as well as the development of the release precipitation.

Special attention will be given to the developments which cause a cloud to grow in depth and width. Cloud and precipitation prediction will be attempted from the numerical model using data from radiosondes and aircraft flight collection.

Additionally, major improvements were made in numerical methods of mapping the ionosphere for the purpose of predicting maximum useable frequencies for telecommunications. The reliability and accuracy of this method developed by ITSA's Ionospheric Telecommunications Laboratory is now at a sufficiently high level that it has been adopted for standard international use. In a unique facility, which simulates the pressure and radiation environment of the ionosphere, atomic and molecular collision processes may now be studied by ITSA's Aeronomy Laboratory under controlled conditions and for greatly reduced costs compared to *in situ* experiments.

Finally, a joint National Academy of Sciences–National Academy of Engineering Advisory Committee to ESSA was established in FY 67. The Committee will review ESSA programs for content, relevance, and technical quality from the standpoint of ESSA's overall service mission.

PROFESSIONAL ACHIEVEMENTS

With the close of FY 67, there were approximately 3,300 professional personnel in ESSA, of whom 800 were working in research and development and engineering activities. During the reporting period, this group produced approximately 1,100 technical publications, chaired about 140 meetings, symposia, or sessions of recognized scientific engineering societies, and served as official U.S. representatives or consultants to international scientific coordinating organizations in over 150 cases. In addition, ESSA's staff produced well over 1 million environmental forecasts and distributed millions of copies of maps, charts, tables, and publications describing the environment.

4 DESCRIBING AND UNDERSTANDING MAN'S ENVIRONMENT

This chapter treats those portions of ESSA's total research, development, and engineering program which are primarily directed toward describing and understanding the environment and understanding the mechanisms of its behavior. The products in this area are hard copy and more or less of a permanent nature. Description may be graphic, as in the case of maps and charts, or it may be alpha-numeric, as in reports and tables. Description products may be used directly (for example, navigation charts) or as a tool for further analysis, e.g., the use of data describing the upper atmosphere (applied in research to improve telecommunications). The application of understanding is usually indirect—for example, when weather forecasting is improved through broader understanding of atmospheric processes.

ESSA's activities in environmental description and understanding are fundamental to its entire service effort. Programs in this area range from the solid earth and its fields, outward to the near-space environment.

THE SOLID EARTH AND ITS FIELDS

Research in this area supports ESSA's service programs and is related to the major objective areas concerned with the Natural Disaster Warning System and Marine Environmental Activities. ESSA's activities in this area are conducted principally by the Coast and Geodetic Survey (C&GS) and the Institute for Earth Sciences (IES) augmented by the Institute for Oceanography (IO) in the fields of marine geodesy and geomagnetism.

The disciplines involved are the descriptive aspects of geomagnetism, seismology, and geodesy.

Geomagnetism

The magnetic field which extends from the core of the earth into outer space must be continuously monitored and recharted. The sources of the earth's principal magnetic field lie deep within its core. These sources change slowly in magnitude and position, requiring some hundreds of years for a cycle to manifest itself. The resulting changes in the magnetic field, however, are great enough to require new charts every 5 to 10 years for precise navigation purposes. Most of the more rapid perturbations of the field, such as those characterized as magnetic storms, are due to electric currents in the ionosphere and higher above the earth's surface. These currents, affected by atmospheric tides, solar wind, and other disturbances originating on the sun, can cause changes that affect telecommunications and navigation adversely.

Geomagnetic Research Facilities

The 15 magnetic observatories of C&GS, distributed from Alaska to the South Pole, together with more than 100 cooperating foreign observatories around the world, constitute an important source of data for geomagnetic research. The Fredericksburg Geomagnetic Center at Corbin, Va., is maintained by C&GS as a facility for the development of instruments and systems, the standardization and calibration of all geomagnetic instruments, and the study of special problems related to the interpretation of data. Analysis and research is performed at the Fredericksburg Center and at the Geomagnetism Laboratory of IES at Boulder, Colo. Research on marine geomagnetism is carried out at the Marine Geology and Geophysics Laboratory of IO at Miami, Fla., using data collected by the C&GS oceanographic fleet.

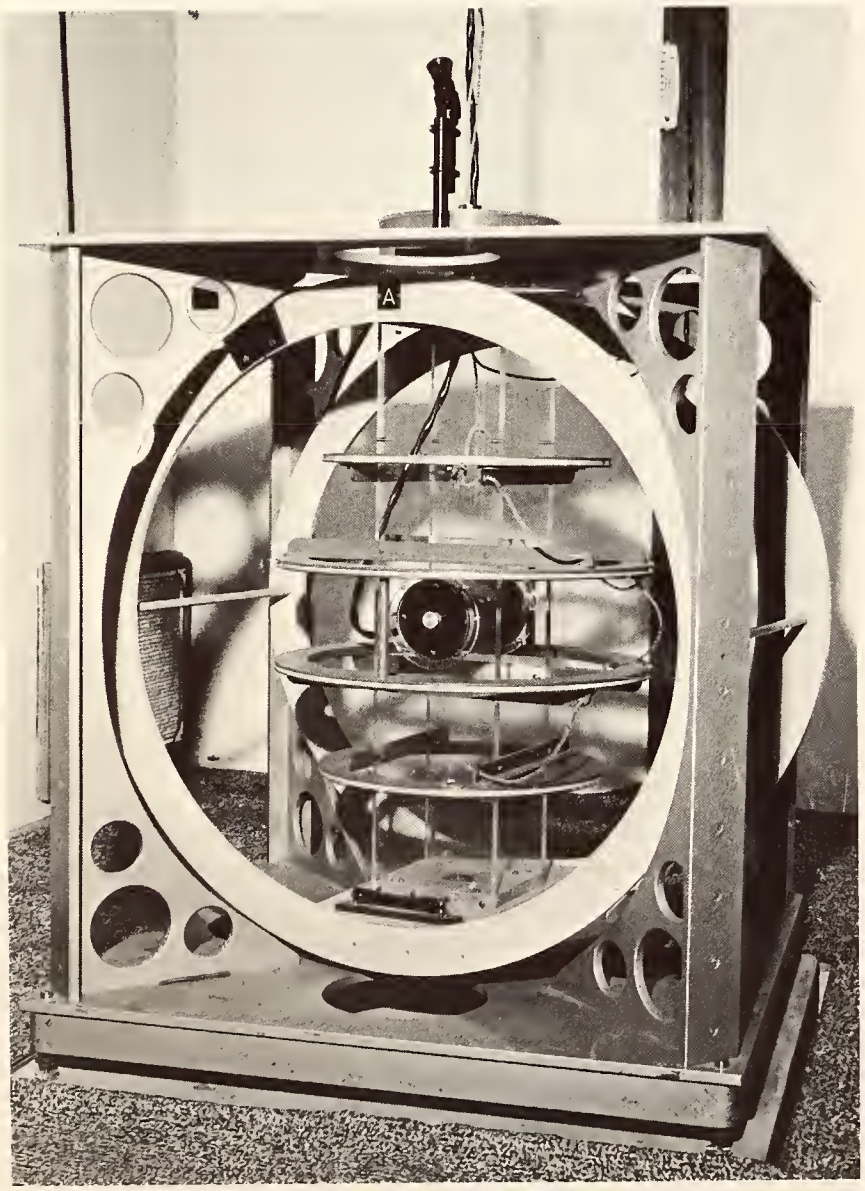
Instrument and Systems Development

The basic instrument used in geomagnetic work is the *magnetometer*, which on land measures three components of the geomagnetic field: horizontal direction and intensity, declination, and vertical intensity. Early magnetometers, the principle of which is still in use today in some instruments, employed optically viewed magnets suspended either freely or on a torsion mounting. Such instruments, although they are still the standard technique for obtaining absolute readings of all components for calibration purposes, require a human observer and are therefore impractical for making continuous observations. During the past decade, the

development of nuclear spin-resonance magnetometers and their adaptation for measuring vector components of the magnetic field, as well as the scalar intensity, have made possible instruments which are faster and more accurate and capable of being used for continuous recording.

Field Instrumentation. To determine a real distribution of the magnetic field, observations must be made at many geographical locations. At selected points, the observations are repeated after the lapse of a few years, to determine secular change. Thus, there is considerable interest in developing portable field instrumentation which can be set up rapidly and which will produce results of superior accuracy under field conditions.

Development of field instrumentation has been pursued through the successful development and fabrication of portable, continuous-recording magnetic instrumentation for use in Antarctica and on repeat magnetic survey work. Continuous-recording magnetic instruments normally are highly sensitive to minute drifts in level and to temperature changes. Through the employment of design innovations and high-quality workmanship, both these problems were successfully reduced to tolerable proportions by the Fredericksburg Geomagnetic Center. Initial success was achieved in the development of a system which was installed in January 1966, at the new U.S. Antarctic Plateau Station, where long-term stability of a rigid platform is extremely difficult to achieve and where a temperature range exists from a few degrees below 0° F to as low as −130° F. A second generation system of improved portability was later developed and put in use by the Repeat Magnetic Survey Party in summer 1966.

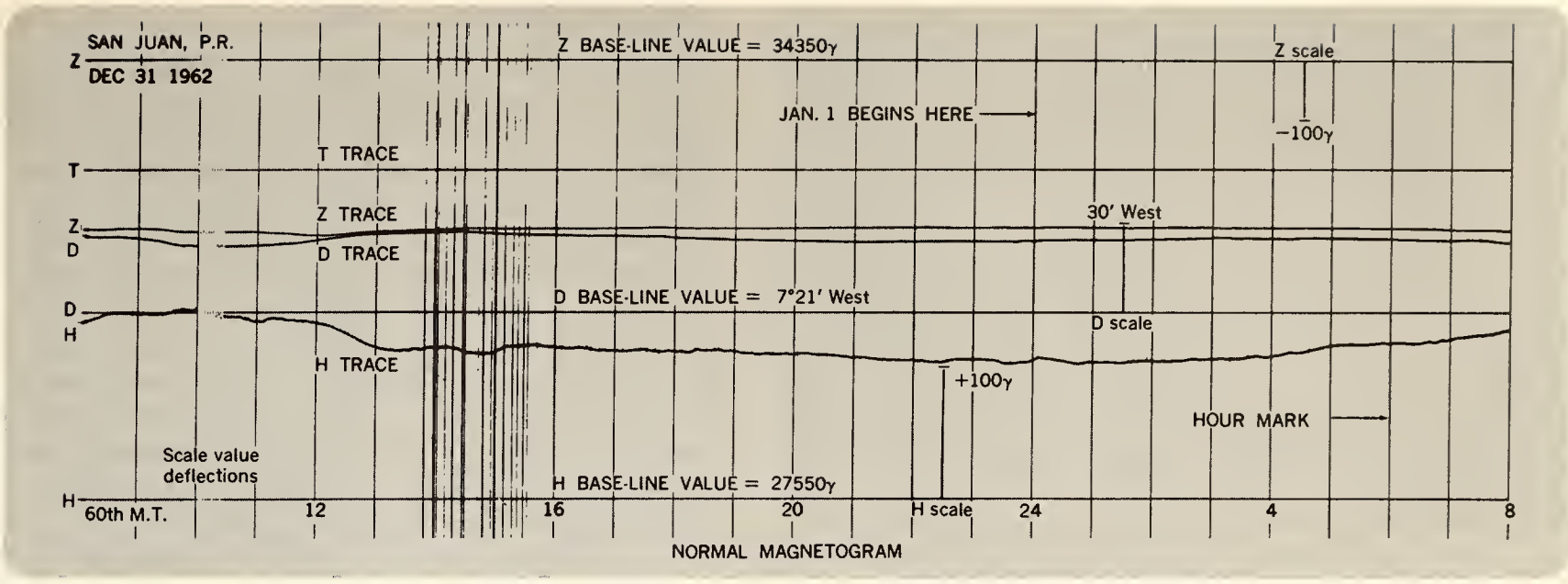


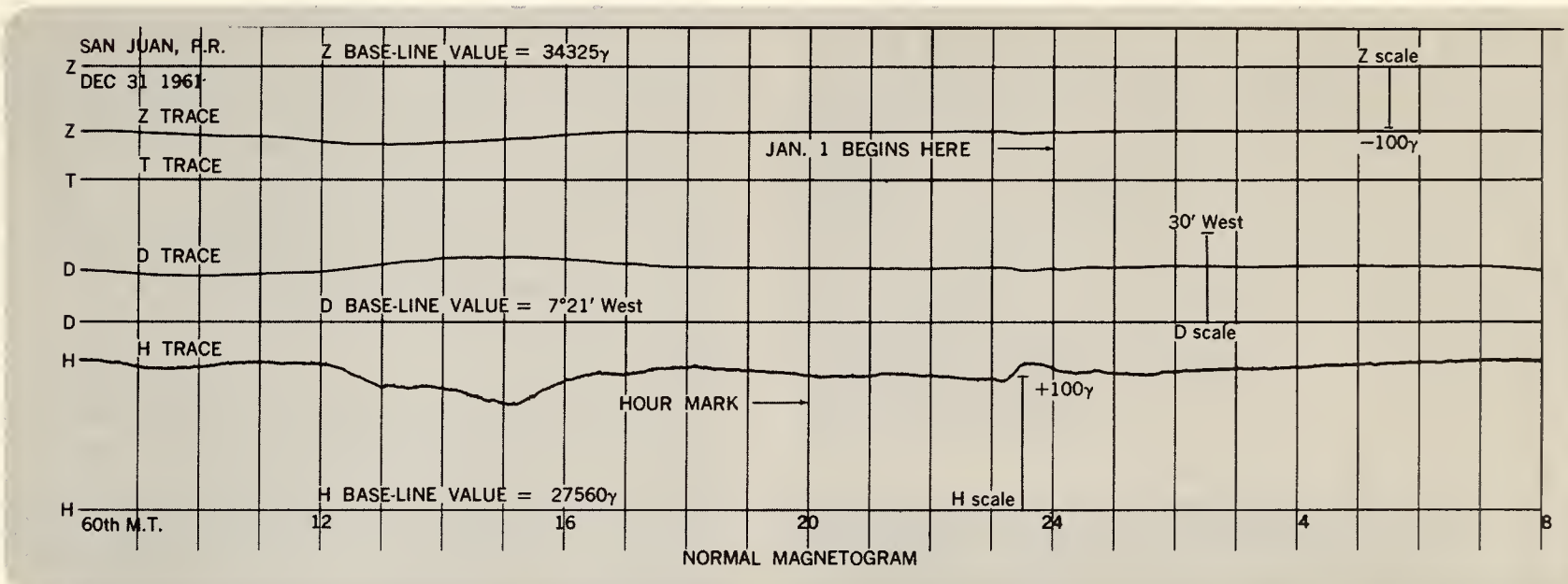
Coil system and detector of a continuously recording vector magnetometer.

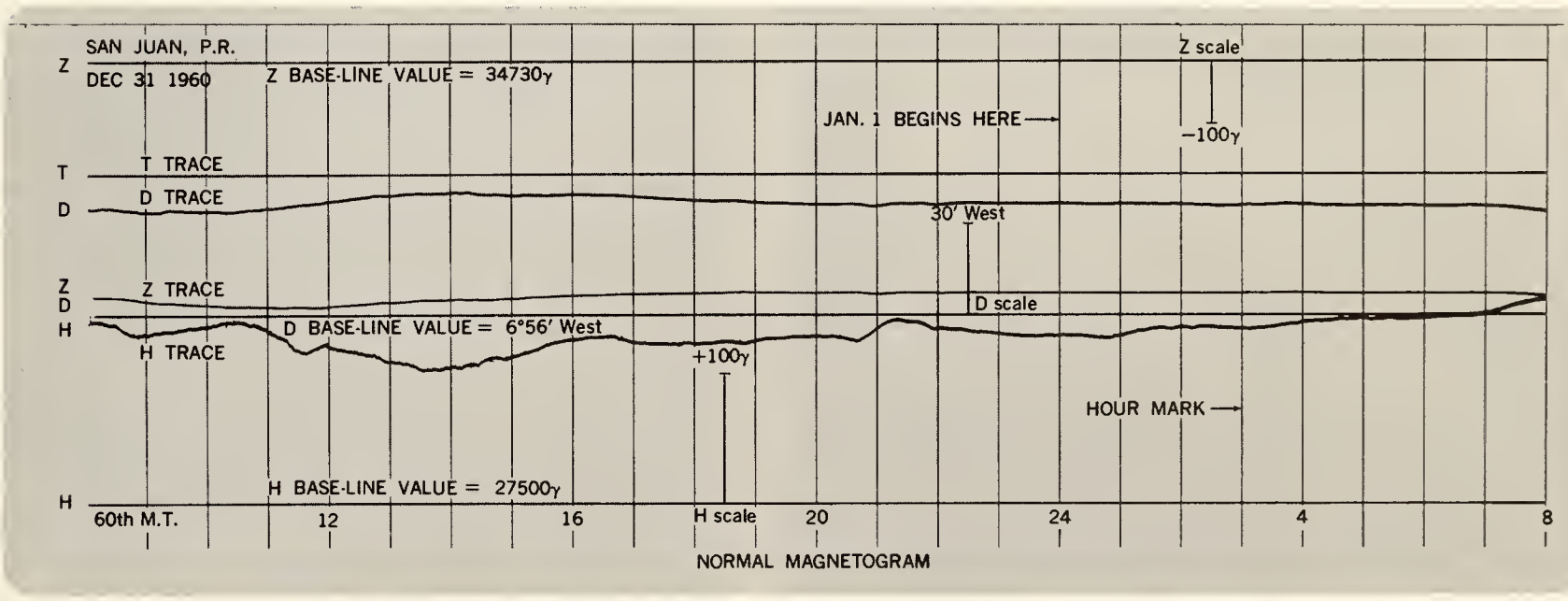
Automatic Magnetic Observatories. A major highlight of ESSA's geomagnetism program during the reporting period was the dedication of the Newport Geophysical Observatory near Newport, Wash. A key feature of the observatory is a new three-component rubidium vapor spin-resonance magnetometer system which detects and records variations in the earth's magnetic field continuously on magnetic tape, in both digital and analog form. This instrument operates without the intervention of an observer, except for calibration and maintenance, but most importantly, it provides a source of continuous three-component data in order that rapid variations may be observed and analyzed with the Observatory's high-speed computers. The instrument operates over a frequency spectrum ranging from near zero (very long period fluctuations measured in months or years) to an upper limit of a few cycles per second. Its sensitivity is high, down to a few hundreths of a gamma (100,000 gammas = 1 gauss). Values of declination, horizontal intensity, and vertical intensity are recorded digitally six times each minute on computer-compatible incremental magnetic tape. The same magnetic elements are also recorded continuously on FM analog tape, resolving variations up to three or four cycles per second. Visual monitoring is provided by pen and ink recorders. The system is equipped with dynamic Helmholtz coil compensation so that even during a magnetic storm the vector components of the field are accurately separated.

A system based on the same general principle, but designed for remote unmanned operation, is now under test and evaluation at the Castle Rock Magnetic Observatory near San Jose, Calif. This device called ASMOR (Automatic Standard Magnetic Observatory—Remote) is a prototype, which, if it meets the requirements for long-term stability and reliability, may lead to the increasing use of unmanned stations in remote locations.

Scanner-Digitizer. It is significant that ESSA's first year of existence saw the conception and in-house development of the first wholly satisfactory semiautomatic system for scanning and digitizing magnetograms. Even though automatic magnetometers are beginning to come into use, the standard instrument used in most of the world's magnetic observatories to record variations in the earth's magnetic field is still the *magnetograph*. This device is an optical magnetometer which must be operated in total darkness. A beam of light is reflected from the mirror attached to the magnets in







Sample magnetograms obtained at San Juan, Puerto Rico. The interval between the samples is 1 year.

such a way as to cast a spot of light on a sheet of photographic paper which is slowly moved past it. Data are reduced manually by measuring the deflections on the magnetogram thus produced and applying the calibration, resulting in a time-consuming operation. The new system eliminates the operation by scanning the magnetogram photoelectrically, applying the calibration and digitizing the result automatically.

Two in-house developed second generation units of the scanner-digitizer were put into routine operation

during FY 67. Concurrently with the delivery of the second machine, a commercial contract was terminated for the manual scaling and digitizing of magnetograms from some 60 magnetic observatories around the world.

At the close of FY 65, the first magnetic field component data were obtained near the surface in deep ocean areas with the successful test of an underwater stable platform developed by the C&GS Engineering Division under the direction of the staff of the Geomagnetism Laboratory of IES. Thirty-day continuous recording of magnetic field data was made 100 miles west of Los Angeles, Calif., in water 5,400 feet deep. Analysis of these data initiated in FY 66 will aid in understanding the global magnetic current system and induction effects in the ocean.

Geomagnetic Studies

Modeling the Earth's Magnetic Field. Using secular change data obtained from the worldwide network of geomagnetic observatories, ESSA scientists have been seeking a mathematical model of the earth's magnetic field which will describe its observed structure and variations with time and permit more accurate forecasts of secular change. When this research effort was first initiated several years ago, a model was envisioned involving 63 current loops in nine different clusters arranged in the core of the earth as sources of the earth's field. This model proved too complicated to manage with the computers then available and a simpler model involving only 20 or fewer dipoles was developed.

The RMS-residual between the field of these dipoles and the observed field is only 28 gammas—a remarkable fit that is difficult to understand since the model sources are so deep within the solid core. During the coming year, this work will be continued, until a final convergent solution is obtained and a rate of change of dipole characteristics is found that will explain the observed secular change.

Marine Geomagnetism. In view of increasing requirements for geomagnetic data from marine sources, an evaluation study of previously acquired marine geomagnetic data was undertaken during the latter half of FY 67 and future years' plans for the acquisition, processing, and mapping of geomagnetic data from marine areas were also begun. Requirements for geomagnetic data from marine areas, particularly from the Continental Shelf, are increasing. Because of the potential influence of the commercial development of the Continental Shelf on the national economy, that area received priority in the initial planning for the future acquisition of data.

Short-Term Magnetic Field Variations. A current flow in the ionosphere in the immediate vicinity of the magnetic equator is related to a greatly enhanced daily variation in the magnetic field. This flow is known as the equatorial electrojet, and recent research has been directed toward explaining this effect.

CROSS-DISCIPLINARY STUDIES

Little is known of earthquake processes and the relation of magnetic field variations to them, but there has been some indication that a significant relationship may indeed exist. If so, magnetic measurements may prove to have an important bearing on earthquake prediction.

A new program was initiated by IES during the reporting period to study the magnetic effects of major stress changes. It includes earthquake mechanism studies; an in-depth literature study on stress patterns in the earth; the magnetic nature of rocks; development of an instrument system to sense and record stress-related magnetic effects; development of analysis capability and analysis techniques; and field test of instrumentation and concepts.

On a grant from the Institute, Stanford University has recently found two or three examples of magnetic events preceding by about a day the occurrence of creep in the San Andreas fault. The events sometimes last nearly an hour and are largest at the station nearest the creep point or earthquake epicenter. Interpretation of these magnetic events may offer one of the better means of predicting impending earthquakes, and present findings will be followed up by increasing the number of sensors during the coming months.

Seismology

Seismology is the study of earthquakes—their causes and mechanisms, their detection and location—and the means for protection of life and property from their effects. The Prince William Sound, Alaska, earthquake in March 1964 highlighted the need for improved understanding of earthquake mechanisms, both to permit prediction of these events and to provide better guidance for the design of earthquake-resistant structures. While this field of study is important, it represents only a portion of ESSA's interest in seismology. For example, knowledge of the means by which the earth transmits shocks and sound waves through its core and mantle is of comparable importance for a number of applications, such as the location and identification of underground nuclear explosions.

Seismological Research Facilities

As in the case of geomagnetism, considerable research in seismology, particularly in the area of description, is performed by using data obtained from globally scattered observatories rather than from a centralized research facility. The World-Wide Network of Standard Seismograph Stations consisted of 114 stations developed by C&GS under the sponsorship of the Advanced Research Projects Agency (ARPA). These stations were operated on a cooperative basis by other nations, with the United States providing instruments and maintenance in exchange for data. In addition, C&GS operates a World Data Center for Seismology to compile archives of film copies of the seismograms gathered from these stations.

This Center has the capacity to copy 275,000 records per year for the master file and to provide, at cost, up to 1,000 copies per day to seismologists throughout the world. In addition to the standard network, C&GS operated 11 stations of its own net and received 230,000 readings per year from over 500 cooperating stations around the globe. The hypocenters of seismic activity located were published twice weekly and distributed to over 5,000 users.

The Survey maintains a fully equipped Seismological Center at Albuquerque, N. Mex., for the development of new and improved seismological instrumentation for both field and observatory application, and for the calibration of seismological instrumentation. A low-frequency dynamic calibration unit has been installed at the Albuquerque Seismological Center. The unit consists of precision vertical and horizontal systems which test all types of seismometers and vibration meters within the frequency range of .001 to 100 cycles per second to determine their actual dynamic response and to discover resonant peaks or spurious signals which might cause a distortion of the output signal at various frequencies.

The National Earthquake Information Center. On August 15, 1966, Dr. Robert M. White, Administrator of ESSA, announced the opening of the National Earthquake Information Center (NEIC) at Rockville, Md., under C&GS. This Center is intended to provide a focal point for the dissemination of seismic information for the scientific and technical community and to the general public.

The first new service to result from the Center is an earthquake early reporting system for the provision of accurate and rapid hypocenter locations and magnitude values. These results are now obtained within a few hours. Presently, the range of the network is essentially the hemisphere centering around the United States. It is planned to expand this network to include reports from selected foreign observatories.

When a large earthquake occurs, the participating observatories respond to their alarms and forward their observations of arrivals and amplitudes to the National Meteorological Center at Suitland, Md. This information is relayed to an on-duty NEIC seismologist who determines graphically the epicenter and magnitude. For earthquakes in the United States, reports are also received from the network of Weather Bureau stations. These facts are released to disaster relief groups and public information users via Weather Bureau dissemination circuits.

The Center also serves as a focal point for other C&GS seismological services. These include studies using the historical files of earthquakes. For example, the preparation of punched card files containing all epicenters previously published by C&GS and a number of other standard sources is well advanced. These cards will contain the latitude, longitude, origin time, data depth, authority, magnitude, intensity, and additional references so that hypocenters with any combination of these parameters can be found.

Publication of a monthly earthquake information bulletin was begun in March 1967 to provide current information about earthquakes of the world and seismological activities of interest to seismologists and to individuals who are not necessarily specialists in this science.

Instrument and Systems Development

Seismograph Development. The basic instrument of seismology is the *seismograph*, consisting of a seismometer and its associated auxiliary equipment to amplify and record motions of the earth as a function of time. The *seismometer*, in its simplest form, is composed of an inertial mass and a mounting which provides restoring force and damping. Motion of the seismometer mass may be sensed mechanically, electromagnetically, or electronically depending upon the degree of sophistication required.

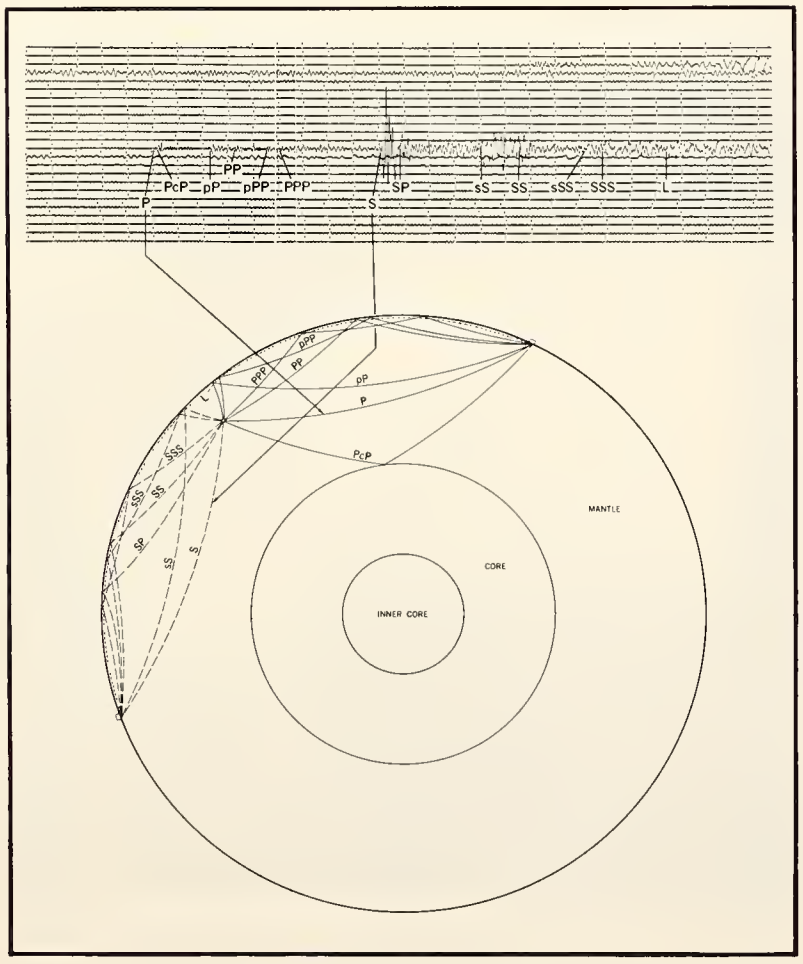
Development and test of several different seismographs was completed during the reporting period to meet service and research needs. The instruments are basically similar in concept but vary in sensitivity, ruggedness, portability, and output design for the applications. For example, the Mobile Seismograph Observatory permits the functions of an observatory to be performed at remote locations, after rapid installation. A recording duration of 30 days permits the operation of a number of these observatories in a regional network by a minimum number of personnel.

At the National Earthquake Information Center, a geophysicist examines a seismogram. Simultaneous recordings from three stations in the Washington, D.C., area are used in determining epicenter distance and direction as well as earthquake magnitude.

Seismological Research

There has been increased interest in seismological research in recent years. The primary factors for this new impetus would include: (1) the International Geophysical Year (IGY) and the International Upper Mantle Project; (2) the Geneva disarmament conferences; (3) the March 1964 Prince William Sound, Alaska, earthquake; and (4) advances in aerospace technology. As a result, geophysicists have been brought together on projects ranging from the use of seismic means for the detection of underground nuclear detonations, to the development of new knowledge of the core and mantle of the earth in support of the Nation's space program. A case in point was a study sponsored by the Executive Office of the President following the Prince William Sound earthquake that focused on using predictions of seismic phenomena to minimize and alleviate earthquake hazards. This earthquake, one of the largest experienced on the North American Continent in recent times, had a magnitude of 8.4, and caused 125 deaths and damage estimated at well over $300 million.

The portion of the research program relating to description and understanding is primarily *teleseismology*, or the study of earthquakes at a distance and, indirectly, the study of the structure of the earth's core and mantle by means of the seismic waves propagated by a disturbance.



The waves from a severe earthquake are recorded on a seismogram (top), which is then correlated with the computed wave pathways through an idealized model of the Earth.

Travel Time. One of the major challenges in teleseismology is the determination of propagation velocities and the travel times of seismic waves for the accurate locations of distant earthquake hypocenters. Prior to 1945, the only source of data for propagation studies was signals from earthquakes whose exact time of occurrence was seldom known. Since 1945, when the first nuclear explosion was detonated, it has been apparent that controlled energy sources represent a great potential in seismic experiments. Knowing the time of occurrence and location of an event permits more exact studies of earth models, station residuals (deviations from theoretical arrival times), hypocenter locations, and energy propagation.

Using arrival times from U.S., French, and Russian nuclear explosions, the universal longitudinal wave arrival times have been revised, with results published by C&GS during the reporting period. Previously, the international norm was based on the classic study by Sir Harold Jeffreys and Professor Keith Bullen, who used existing seismic data from earthquakes. Figure 2 gives the relationship between the old and the new values. Source and station corrections have been computed and it may be seen that real surface focus travel times are early by about 2 seconds and at 60° latitude, arrivals are earlier by another second. This early arrival at 60° implies a change in the earth model at about 1,600 km. depth, or about mid-mantle. The efforts of IES and C&GS to refine fully all aspects of the travel time values have continued in association with university and other research groups under a committee sponsored by ESSA.

A concurrent study of measured amplitudes was carried out which revealed marked and persistent deviations from the conventional curves showing attenuation of signal amplitude with distance. In general, the United States, west of a line from Glacier National Park to El Paso, produces lower seismic amplitudes—for teleseismic events of a given magnitude—than would be expected normally. Two other areas of comparatively low signal strength are tentatively located in the Wichita-Ouachita Mountain belt and the eastern portion of the Appalachian Mountains. Higher than usual signal amplitudes were found in the Dakotas, southwest Texas, and the northern Lake Michigan region.

One of the most significant sources for study of seismic waves was the LONGSHOT explosion, detonated under Amchitka Island in the Aleutian Islands. This explosion was well recorded throughout the world and occurred in a highly seismic area where there is a wealth of natural earthquake activity, the records of which may be compared directly with those from this explosion. ESSA participated in the planning as well as the recording and analysis of data for this shot, and the study produced important new information. In general, the results showed that arrival times were substantially earlier than predicted by the Jeffreys–Bullen curves, even after the 2.5-second correction estimated from previous data.

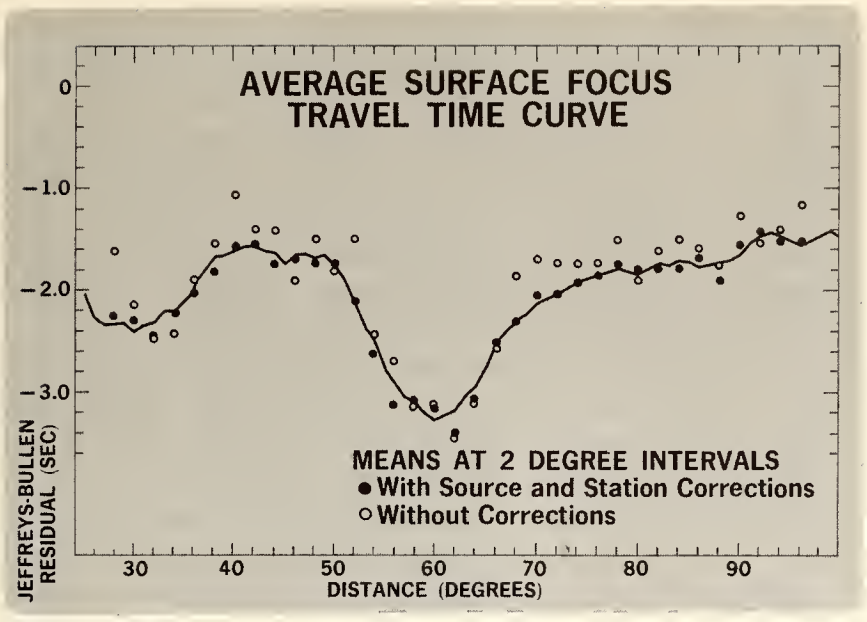


Figure 2. A comparison between the "classic" Jeffreys-Bullen travel-times and more accurate values recently determined by the Coast and Geodetic Survey.

Statistical variance residuals ranged from as high as 6.5 seconds to about 2 seconds. As a result of this study, a new traveltime curve has been developed by the ESSA-sponsored traveltime committee.

Hypocenter Location. The location of a hypocenter is determined by comparing arrival times of seismic waves from a number of stations. Because the vast majority of earthquakes are minor in nature and only detectable by instruments, the task of comparing data from hundreds of stations and identifying related patterns is formidable, and requires the use of computer processing. A new C&GS computer program for the IBM 7030 permits much more rapid and detailed analysis than in the past, and as a result, the number of hypocenters located per year has risen from 1,500 to over 6,000. This means that a more complete seismicity pattern is being developed which will lead to statistical analyses of energy release with time in various areas. This new program should make a significant contribution to the definition of causative factors and earthquake mechanisms and to the prediction of earthquakes.

A long-term project to revise the tables of P-wave (longitudinal or compression-rarefractional waves through the earth) travel times conducted by an ad hoc committee of seismologists both in the United States and abroad was completed during the reporting period. Most of the preliminary data compilation and analysis was performed by an IES scientist, who also provided more accurate estimates of earthquake focal depths. On the basis of a large amount of arrival time data supplied by C&GS, hypocenters of earthquakes were recomputed. Residuals from 278 large earthquakes, carefully selected for uniform distribution, and 13 large explosions were combined to obtain final corrections in the trial travel times. The new tables of travel times will be published in the Bulletin of the Seismological Society of America. They will be used to compute the hypocenters of earthquakes and explosions; the residuals from these computations are used to interpret the local and regional characteristics of the crust and mantle. The velocity distribution table and the new estimate of the depth to the core will be used by geophysicists to obtain improved estimates of the density, distribution, rigidity, and incompressibility at various depths within the earth.

Structural Studies. Crustal structure studies associated with the Prince William Sound aftershock sequence have allowed the development of local travel time curves for use in that highly seismic area. Precise determination of hypocenter depths allows more accurate computation of surface epicenter locations than previously obtained by teleseismic means. A new device computes hypocenter locations from local station data and displays the results graphically.

A catalog of fault plane solutions is being developed for various areas from seismic data to provide information on the tectonic forces which predominate in a given region. This information relates directly to the problem of earthquake prediction and provides primary data for studies of the tsunami-generating mechanism.

Continuous efforts are being made to translate the results of research studies into improved services. A recent study of the capabilities of seismograph stations provides immediate information regarding the stations most likely to record an earthquake as soon as its general epicenter on the earth's surface is known. Readings from these stations can be obtained and the final epicenter determined more rapidly than was previously possible.

Geodesy

President Johnson, in announcing the formation of ESSA in July 1965, pointed out that one of its key missions is "to determine the size and shape of the earth." At first glance, this mission might appear to be one of purely scientific value to satisfy man's curiosity about his environment. In reality, however, such a determination is essential for many practical purposes, for in no other way can the distance and direction between widely separated points on earth be found, nor can satellite orbits be predicted without this information.

For small regions it is possible to measure distance and direction by means of a *plane survey*, which ignores curvature of the earth and variations in gravity between the points. For large distances, however, the determinations must be made by a *geodetic survey*, which takes into account not only the curvature of the earth but also variations in the magnitude and direction of the effective gravitational force due both to the earth's rotation and local anomalies. The need for such surveys results from the fact that gravity variations cause a deflection of the vertical direction, as determined by a plumb bob, from that which would be determined by purely geometrical means. Thus, astronomical observations related to this apparent vertical direction would lead to in-

correct values for latitude and longitude and variable apparent locations for the center of the earth and its axis of rotation.

To solve these problems the geodesist first must determine the *geoid*, a theoretical surface that is everywhere perpendicular to the effective gravity force and over which the gravitational potential is constant. For convenience, the geoid is taken as the particular surface which coincides with the mean sea level of the oceans. This surface is significant because all measurements of the vertical by plumb bobs or bubble gages are with respect to it.

The geoid, like the surface of the earth itself, is irregular, and hence is not useful as a basis for mapping. A common reference or *datum* to which surveyors at points distant from one another can relate the local configuration of the geoid is thus required. This datum takes the form of a regular mathematical surface, an ellipsoid, which makes the best fit to the geoid at widely scattered locations, and can be used as the basis of the coordinate system for latitude and longitude. In using it the geodetic surveyor must determine both the difference in elevation between the ellipsoid and the geoid, known as the *undulation of the geoid*, and the angle between the two surfaces, known as the *deflection of the vertical.*

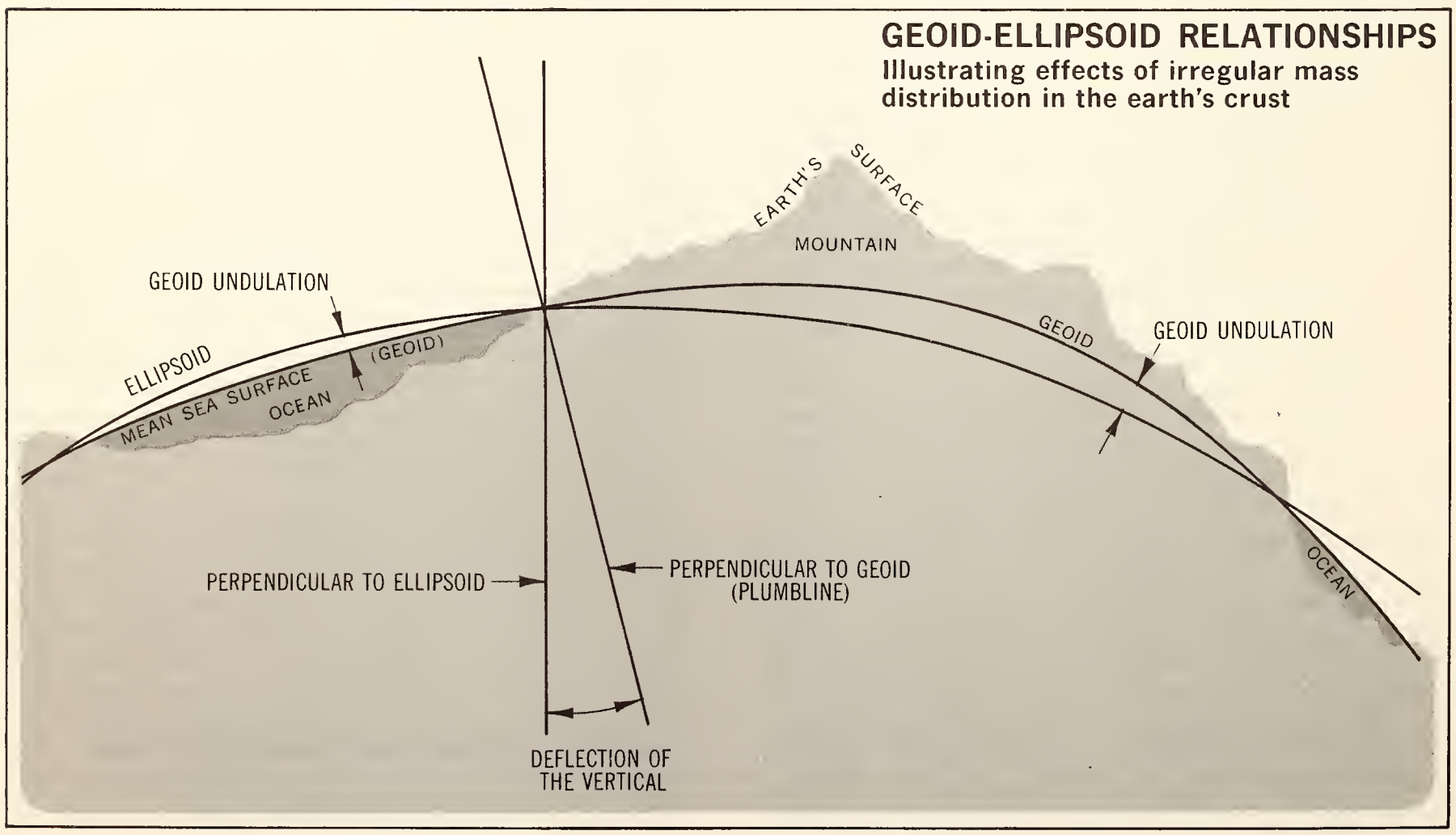
In the past, where requirements for accurate knowledge of relative positions were national or regional, ellipsoids providing a best fit were chosen for local convenience. However, since World War II, when it was discovered that European and American charts were badly out of alinement with one another, there has been a growing realization of the need for a single World Datum or ellipsoid, to which all nations would agree to refer survey measurements. Because one regional ellipsoid in general provides a poor fit in any other region, the attempt to arrive at a World Datum remains a major challenge to geodesy.

Prior to the advent of the satellite this task was almost insurmountable, since the relative positions of continents could not be accurately known. Triangulation by means of artificial satellites thus offers a unique means of determining geometrical positions and shape, while avoiding cumulative errors.

Research Facilities

As in the case of geomagnetism and seismology, the earth itself constitutes the laboratory for geodesy. Facilities are maintained in instrument development, testing, and calibration, and for data reduction and analysis. The C&GS maintains a number of particularly accurate control points in various parts of the United

Because the earth is not a perfect sphere, accurate geodetic measurements cannot be taken by referring only to its surface. Theoretical surfaces (the geoid and the ellipsoid) compensating for local departure from the theoretical geometric and gravitic values must be developed and continually updated.



States where location, elevation, and strength and direction of the gravitational field are known with great precision. These points are used for the testing and evaluation of new instruments, as well as for the calibration of field equipment. In addition, underwater gravity ranges are maintained on both coasts. A photogrammetric test and calibration range is maintained near McClure, Ohio, where both cameras and systems may be evaluated. Finally, the Office of Geodesy and Photogrammetry of C&GS maintains a laboratory at Rockville, Md., for the development of new instruments, and the Satellite Triangulation Division has established a special development, testing, and training facility at Beltsville, Md.

Instrument and Systems Development

Precise Measurement of Distance—The Geodimeter. Two types of basic measurements are made in geodetic surveys—one is length and the other is direction. To achieve a desired accuracy in location of one part per million, extreme precision is required. Lengths are measured by a device known as the *Geodimeter*, an electro-optical instrument which essentially times the passage of light along the line between two points and back again. The Geodimeter depends for its operation on a precise knowledge of the speed of light, and although the speed is known quite accurately under given conditions, it varies with a number of atmospheric factors as the index of refraction varies.

To give an idea of the problems in achieving accuracy: A change in the velocity of light of one part in a million is produced by a variation of the integrated mean temperature by 1° C; of the mean pressure by 2.5 mm Hg; of the mean humidity by 20 mm Hg of vapor pressure. The dependence of light velocity on color is of the order of 0.6 parts per million per 100 Å. Taking into account all factors, the uncertainty in the velocity of light under optimum conditions is considered to be about one part in a million, so that this uncertainty remains a controlling factor in attempts to obtain overall systems accuracies of this order of magnitude.

During the reporting period, C&GS constructed a *laser-Geodimeter* which overcomes some limitations of the mercury vapor Geodimeter by improving the range of visibility, particularly in the vicinity of large urban centers. The laser possesses greater intensity and is monochromatic, which means that the velocity of light will not have variations as a result of color. During tests, this device gave at least a 50-percent increase in range over the mercury vapor Geodimeter. Distances up to 42 km. were accurately measured under normal atmospheric conditions at night. It is also estimated that ranges of at least 21 km. can be measured during daylight hours. During FY 67, conversion was initiated of 10 mercury vapor Geodimeters to laser light source, with delivery of the first two modified Geodimeters scheduled for early FY 68.

At ESSA's Institute for Telecommunications Sciences and Aeronomy, a physicist studies the effect of atmospheric dispersion on a beam of light.

Another aspect of the problem of the uncertainty of the velocity of light is the problem of variations in the index of refraction with time as a result of changes in the atmosphere. This problem is particularly acute in mountainous areas and other regions characterized by turbulent atmospheric conditions. The Institute for Telecommunication Sciences and Aeronomy (ITSA) has built and tested a device which employs two different wavelengths of light to give solutions which are almost independent of variations in the index of refraction.

Gravity Meters and Test Facilities. Absolute gravity meters in the United States are usually of the pendulum type, by which the acceleration of gravity is calculated from the period of a pendulum of precisely known length. Normally, these meters are located at base stations and serve as controls for the relative gravity meters, or gravimeters, used in the field. The latter, usually of the spring balance type, are extremely accurate, and when properly calibrated, are capable of measuring the acceleration of gravity to within .01 milligal (1 gal = .001 standard earth gravity).

Ground-based measurements are capable of achieving this instrumental accuracy under proper conditions, but the problem is much more severe when gravity must be measured on a moving platform—for example, in the case of marine geodetic observations. Until recently, marine geodesists had to be satisfied with accuracies of the order of 5 to 10 milligals, but an improved system developed with ESSA guidance was recently field-tested aboard a naval vessel. Confirming previous C&GS accuracy determinations, the Navy's test yielded

a mean square error of less than plus or minus 1 milligal in calm seas. The major error source was attributed to navigation rather than instrumental error *per se*.

Geodetic Research

Marine Gravity and Geodesy. To obtain datum control for the East Coast Upper Mantle Project, an offshore gravity range was established in the vicinity of Cape Charles–Wallops Island, Va. Gravity values were obtained with a bottom gravity meter and positions were established using an electronic positioning system. It is estimated that gravity values at the surface can be interpolated to better than 1 milligal mean square error in the vicinity of Cape Charles. This range is suitable for the evaluation of shipborne continuous reading gravity systems. Gravity stations, in addition to those established at a 3-mile spacing in the vicinity of Cape Charles, were established at wider spacings from Cape Hatteras to Cape May. These stations will serve as calibration points, or as control for gravity values obtained aboard surface ships during the Upper Mantle Project. This project involves soundings, depth measurements, corings, ocean bottom scanning, and heat flow measurements. It was carried out in FY 66 and 67 off the west coast of the United States between the latitudes of 35°–39° north and ranged from the shore to about 500 miles offshore. The Atlantic portion of the Upper Mantle Project will consist of a belt of observations 180 nautical miles wide along a great circle from Norfolk, Va., to Cape Blanc, Mauretania, Africa.

To encourage the economic development of the continental shelf, a program was undertaken to acquire geophysical data and establish geodetic control in this region. The first areas of development, between Cape Cod and the northern coast of Maine; and between Jacksonville, Fla., and Cape Kennedy, Fla., were surveyed during the reporting period. The survey utilized bottom gravity stations at 10-mile spacings which served as a base for a rough reconnaissance map and provided the datum control for a more detailed survey to be accomplished by continuous reading shipborne gravity meters. To establish geodetic control in these ocean areas, a subsurface geodetic marker was implanted in the vicinity of Grand Manan Island. The feasibility of additional markers will be considered and existing navigation systems will be evaluated for geodetic purposes.

Marine geodesy will be of continuing and growing importance as the need for more and more accurate worldwide networks grows. The vast majority of the surface of the earth is covered by the seas, where geodetic observations must be made from water-based platforms. The underwater stable platform developed in connection with ESSA's geomagnetism program is expected to play an important role in forthcoming marine geodetic surveys, and other developments may be expected in the future.

Satellite Triangulation. The importance of satellite triangulation was stressed earlier as a new and unique means of establishing geometric relationships between points on the surface of the earth without reference to the gravitational field. Satellite triangulation has been under development for a number of years and has been successfully tested on a continental basis using the satellites ECHO I and II, and PAGEOS. However, there are a number of problems yet to be solved for both current and future programs.

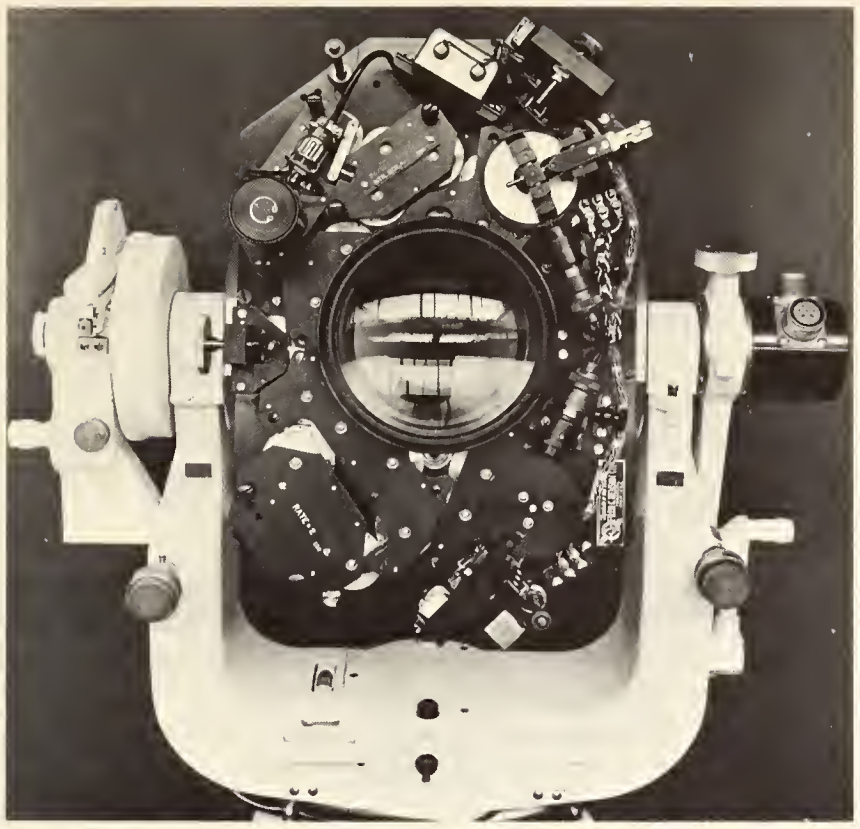
Satellite triangulation, as planned by ESSA, is based on the use of high-orbit satellites, and hence leads to geometric measurements largely independent of gravitational variations and anomalies. In addition to the value of this type of measurement to the establishment of a world net, a reference is provided for subsequent experiments with low-altitude satellites which will measure perturbations and thus provide a means for defining the gravitational field of the earth. The ultimate selection of an optimum ellipsoid for the World Datum will require such gravity measurements, in addition to satellite triangulation data. A number of surface observations of the magnitude and direction of the gravitational force also must be made to define the geoid on a global basis. With geometric position known independently, errors will no longer be cumulative, and the World Datum may be defined with the required accuracy of one part in a million.

In order to use the triangulation technique to determine distance and direction, it is not sufficient to measure angles only. At least one side of each triangle must be known with great accuracy, either by measurement or by calculation from previous triangulations. To avoid cumulative error, direct measurement of distance must be made at several different places in a network.

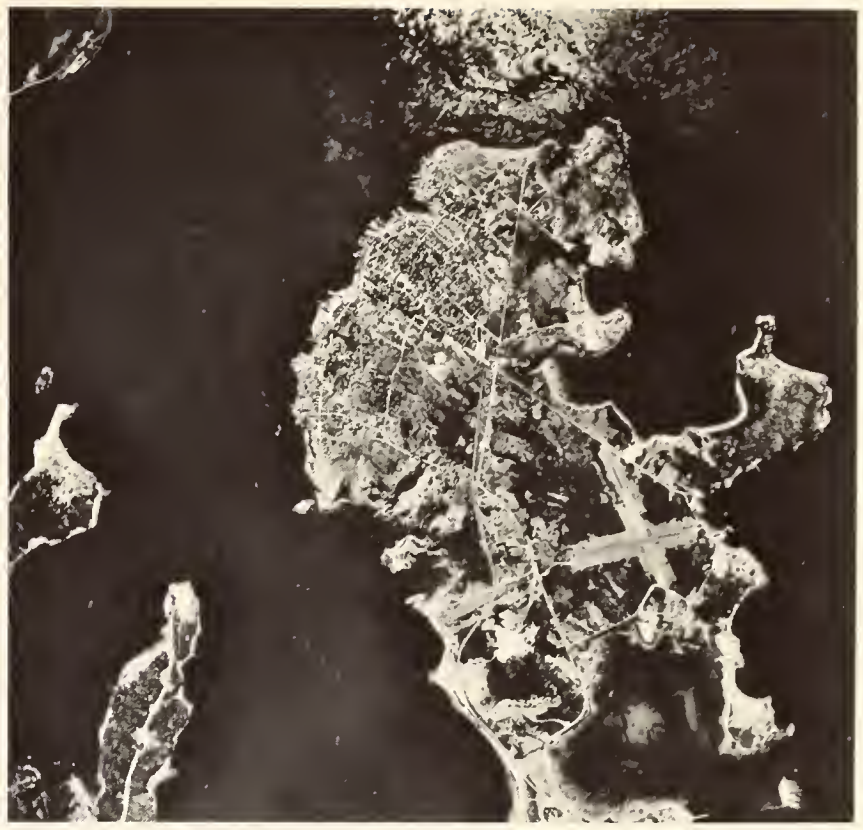
In the case of satellite triangulation, scale may be determined from existing geodetic survey data, although it is preferable to introduce scale by the establishment of long geodimeter base lines using modern equipment. The plan is to incorporate for the world net at least three and preferably four accurately scaled legs distributed more or less uniformly around the earth.

The technique consists of photographing a satellite with high precision cameras simultaneously from two or more ground stations separated by a few hundred miles, or, up to two or three thousand miles. With the satellite and star images on the same plate, it is possible to infer the direction of the satellite from the ground stations by determining its apparent astronomical right ascension and declination. After a series of observations from a set of stations, the lines of direction to the satellite form planes, the intersection of which represents a straight line between the ground stations. Because the directions of the planes are known, the direction of their intersections is also known relative to the spin axis of the earth. The network of triangles thus developed will ultimately span the continent and encircle the globe.

A considerable effort is underway in the establishment of sophisticated computer programs. A new single-camera simulation model has been completed which,



The BC-4 satellite tracking camera, showing the high-precision gearing system required for disk shutter operation.



Accurate measurements made directly on glass diapositive plates permit the use of aerial photographs to map coastal areas.

besides its use in satellite triangulation, has proven to be most effective for the analysis of high precision photogrammetric sensors.

A large number of error propagation studies for the contemplated worldwide geometric satellite triangulation program have been completed, which have led to better means of selection of the sites to be incorporated into the program.

Initially employing satellites ECHO I and II, the program to develop a worldwide geodetic network is now underway. A scheme involving 21 stations has been completed, spreading from northwest Canada and the United States, to Antigua, Norway, and Scotland. Plans have been developed to provide densifications of satellite triangulation by stations spaced on the order of 1,000 km. apart, within the world net, over the various continental datums.

A cooperative program of the Department of Defense with NASA and the Department of Commerce led to the successful launch of a sun-reflecting 30-meter diameter balloon satellite known as PAGEOS.

During the past year, considerable progress was made toward the goal of a worldwide geometric satellite triangulation network, using the PAGEOS satellite. A skeleton framework of *events* (events refer to the simultaneous observations from the earth by one or more camera systems) on the network of stations in Iran, Sicily, Germany, Norway, the Azores, Thule, Maryland, California, Washington, and Maui was adjusted and it produced the required high degree of consistency. The adjusted network now consists of 87 acceptable satellite events at 11 stations.

Photogrammetry

Photogrammetry is the science of making reliable measurements of the earth's surface by the use of photography. ESSA makes use of the rapid synoptic data gathering capability of aircraft for its photogrammetry program. The results of photogrammetric analysis are used for densification of geodetic networks, coastal mapping, investigation of surface currents relating to the interaction between the atmosphere and the oceans, and the support of Continental Shelf studies.

Photogrammetric Instruments and Systems

C&GS has pioneered the application of color aerial photography to photogrammetry, assisting and encouraging the manufacturers of film, cameras, glass diapositive plates, and stereoscopic plotting instruments to provide the means for attaining metric fidelity and photographic resolving power in color equal to or better than that of black and white films in general use for aerotriangulation.

Photogrammetric Camera Systems. Two significant advances in the state-of-the-art in photogrammetric camera systems were accomplished by ESSA during the reporting period. The first came from an evaluation and analysis of the characteristics of aerial film distortion. As a result of this evaluation, a mathematical model was developed which made it possible to compensate for the distortion by using fiducial marks in the aerial camera. The second advance came with the development of an ultra-precise method of camera calibration using thousands of photographic images of stars to determine all elements of interior camera orientation and all metric lens defects with a statistical probable error of only one micron.

A new polyparametric photogrammetric camera orientation and calibration computer program has been tested successfully and will soon be operational. It can determine as many as three sets of external orientation parameters (camera angles) from stars which were photographed during the pre-event, event, and post-event exposure sequences and to select and homogenize those sets of parameters which meet the criteria of statistically significant consistency. By this means, any abrupt movements of the camera or plate during the exposure sequence can be detected and analyzed for the purpose of either removing the inconsistencies where possible, or rejecting the events for proven cause.

The Geodetic Laboratory of IES has applied computer programs in another aspect of the problem of obtaining greater accuracy, in studying the propagation of systematic residual errors in the process of reconstructing the actual earth geometry from strip photographs. These attempts constitute the first systematic investigations into other than random error propagation and are of special significance when considering complex geodetic-photogrammetric measuring systems for resources studies.

Photogrammetric Research

ESSA's research effort in photogrammetry is directed toward the development of a method which would enable C&GS to supplement or replace costly and relatively slow conventional triangulation techniques with aerial three-dimensional photogrammetric triangulation techniques for grid *densification*, i.e., for establishing the necessary detailed grid in between the major control points established by conventional triangulation.

Various aspects of this work are closely connected with feasibility studies conducted in connection with NASA's APOLLO Application Program for utilizing space technology in an earth-oriented resources program and with respect to the contemplated Lunar Exploration Program. It appears at this time that a geodetic-topographic mission on the moon would, to a large extent, depend on the development of extremely precise photogrammetric triangulation methods.

A method had been developed by C&GS for the derivation of ocean current velocity data by photogrammetric measurements in which time-lapse photography was used and was controlled for individual photographs and flights. In an experiment during FY 67, the horizontal position of the C&GS Survey Ship *Peirce* was obtained from transmitters located on the coast. The ship remained at the center of a group of floating targets for each flight of photographs and its image served as the horizontal control. Azimuths were taken of a few of the masted floating targets at the time of each flight of photography. Thus, the photographs were controlled in position and in azimuth. Scale was controlled by maintaining a prescribed flight altitude by use of the airplane's altimeter with base barometric correction from the survey ship. The photography was taken in color at 1:20,000 and at 1:30,000 scales at one-half hour intervals for a 2-hour period. The photographs were overlapped approximately 80 percent in order to furnish redundancy of data. Floating targets were of three types—masted, rectangular, wooden panels; aluminum powder; and Rhodamine dye. These were dispensed by the survey ship just before the photography was started and along a 3-mile long line normal to the Gulf Stream.

Results of this experiment were very encouraging with an indicated accuracy of better than 0.05 knot. From this experiment have come new ideas for applications to other areas where synoptic current surveys are required. Also, during the reporting period, crustal movements studies at Anchorage, Alaska, were made using analytical photogrammetric techniques.

Analytic aerotriangulation. Analytic aerotriangulation is a method for accurately determining the ground positions of objects on a strip or block of overlapping aerial or satellite photographs by means of digital computations based on photograph coordinate measurements. It is a major branch of the science of photogrammetry, which has developed rapidly as a result of the availability of large electronic computers.

The accuracy of analytic aerotriangulation is directly dependent on the precision of the aerial photograph, which is treated as though it were a true central perspective projection. The task of a research and development project for photogrammetric systems development is to make mathematical compensation for all physical departures of the aerial photograph from a true central perspective. Some of the principal phases of this project deal with the physical deficiencies of cameras, such as lens distortion, optical resolving power, focal plane deformation, photographic resolution or sharpness, and film distortion.

C&GS has had an operational system of analytic aerotriangulation for strips of aerial photographs since 1962. Although this system has provided substantial improvement over the previous analog methods of measurement, recent work on the mathematical treatment of the basic formulation has resulted in further refinement of image coordinate data, strip adjustment, three-photo aerotriangulation, and analytic block aerotriangulation.

The Survey has recently completed an operational system for the analytic aerotriangulation of large (200-photograph) blocks of aerial photographs. In this system, the simultaneous orientation of all photographs is performed up to as many as 200 prelocated geodetic control points, and the three-dimensional location of any number of new terrain points is accomplished by computer. The method of least squares is used for the minimization of observational errors. This technique is currently being applied to such precise photogrammetric operations as determining the relative movement of the earth's crust at Salt Lake City, Utah, and Anchorage, Alaska.

THE OCEAN AND ITS SOLID BOUNDARIES

The interaction of the land-sea boundary involves studies of sediment transport and characteristics, the

development of prediction systems, and continental shelf applications. This field of investigation thus necessarily involves an interdisciplinary effort among ESSA's components.

Descriptive Oceanography

ESSA's programs in this area are the responsibility of the Coast and Geodetic Survey and the Institute for Oceanography of the Institutes for Environmental Research. The disciplines included in this area are hydrography and bathymetry, marine geology, and studies of the interactions between land and sea on shores and beaches and in estuaries.

In the field of oceanography, terminology is a particular problem because the same words are given different meanings by different groups. In keeping with the growing practice within the Federal Government, *oceanography* is defined broadly as comprising all ocean science and engineering, including the study of the oceans' boundaries of air and earth. *Hydrography* is the description of the physical features of the ocean with special reference to nautical charts and the safety of navigation, while *bathymetry* is the science of defining the topographic contours of the ocean bottom; these two fields thus differ largely in purpose, rather than in methodology or scope. *Bathymetric maps* show contours of bottom topography, but do not in general show nontopographic navigational information which characterizes *nautical charts.*

Research and Development Facilities

Shore Facilities. ESSA maintains several major shore facilities for research in descriptive oceanography: IO with its Marine Geology and Geophysics Laboratory and Physical Oceanography Laboratory at Miami, Fla.; its Land and Sea Interaction Laboratory (LASIL) located at Norfolk, Va. (at the site of the Atlantic Marine Center of C&GS which also participates in the program); and the Pacific Oceanographic Laboratory at the Pacific Marine Center at Seattle, Wash. At these laboratories, equipment and instrumentation are available for physical and chemical analysis, in addition to extensive special purpose data reduction and analysis equipment, including computers and plotters for processing hydrographic data.

Ship-Based Facilities. In the field of oceanography, shore facilities are only one element of the total facility complex required to perform research. In addition to a number of ships and small craft for in-shore surveys, ESSA maintains a fleet of special purpose oceanographic survey vessels which serve as floating research laboratories as well as platforms for gathering data. The largest and newest of the fleet, the *Oceanographer* and *Discoverer* launched during the reporting period, are equipped with complete laboratory instrumentation for oceanography, meteorology, and other fields of environmental science. In addition, these vessels have on-board computers which provide both a data reduction capability and information for ship operation and navigation. Other ships now under construction will be similarly equipped.

Instrument and Systems Development

A variety of both general and special purpose instruments and systems are needed to perform oceanographic research; and accuracy, efficiency, and economy must be continually improved. Although individual laboratories contract for the development of special purpose instruments from time to time, most development of oceanographic equipment is performed by the Engineering Division of C&GS.

Oceanographic Data Acquisition Systems. In addition to developing new systems, such as the ones installed on the *Oceanographer* and *Discoverer*, ESSA has established a continuing program to refit older hydrographic and oceanographic ships with improved data logging and processing systems. These systems accept data from various sensors and convert them to machine form for processing either aboard ship or at processing centers ashore. All major vessels of C&GS are now equipped with some form of data logger. An improved system, which uses an on-board computer logging and plotting system to analyze data, has been designed. This system was installed and used successfully on board the ship *Whiting* during FY 67 for field operations on Long Island Sound. All components necessary to record depth values and position data (correlated by time) are collected, processed, and displayed in real-time. The *Oceanographer* also used a centralized computer system for navigation and the collection of oceanographic data on its global trip. Planning and design of a computer complex for the *Researcher* is now underway.

Buoy Systems: ODESSA—TICUS. The ODESSA System uses buoy-supported instruments to measure various parameters such as temperature, salinity, current speed and direction, and depth of observation. Designed for coastal studies (although having a deep-ocean capability) the system is capable of making vertical profile measurements of these parameters at eight different depths simultaneously. Recordings can be made in the buoy on magnetic tape or telemetered on demand to shore- or ship-based facilities and there recorded on magnetic tape. With this two-mode capability, the system can also be used for internal buoy recording with occasional performance monitoring by interrogation. All operations of the ODESSA System are automatic in programming and recording. Two successful 30-day evaluation tests of the ODESSA System were made by the Engineering Division during FY 67.

The TICUS (Tidal Current System) developed simultaneously with the ODESSA System is now operational and is being used on current surveys by the ship *Marmer.* TICUS has common features with ODESSA data-logging equipment, but is simpler, since it is designed only to measure currents for circulatory surveys.

Current Meters. The development of a prototype model of a high-velocity current meter is approximately 75 percent completed. This meter is intended for those stations where velocities exceed four knots and measurements from conventional meters are difficult to obtain.

Adoption of an internally recording current meter for use on vessels not specifically assigned to current measurements was initiated during the reporting period. These meters operate with only limited attention from ship personnel, hence their use does not interfere with hydrographic or other oceanographic operations.

Electronic Data Processing. A recently installed computer-plotter system at the Pacific Marine Center of C&GS has the capability of producing a hydrographic *smooth sheet* (basic bathymetric representation from which charts are later made) directly from raw data inputs from any survey conducted with electronic "range-range" control of position. (Range-range systems involve measurement of distance from two or more shore points.) The tapes furnished to the system are coded with all pertinent data relating to position and depth as a function of time, and corrections for instrumental error, tide, and other variables similarly correlated with time. This information, together with correction for the velocity of sound in sea water, is fed into the computer-plotter system. All corrections to soundings and positions are automatically applied and the location of each depth is computed in terms of geographic position and then in terms of the X, Y coordinates of the plotter.

Automated Cartography. Similarly, C&GS has made significant progress in the field of automated cartography, one innovation being the production of sections of chart manuscripts using automatic scribing plotters. The topography and hydrography for nautical charting can now be applied to new constructions by automated techniques.

The speed and accuracy of automated techniques will substantially reduce the man-hour requirements for compilation and drafting. Computer programming will permit accomplishment of the following objectives:

a. Construction of all basic map projections, and systems and navigational lattices.

b. Plotting and scribing most geographic symbols.

c. Computation and scribing bathymetric contours.

d. Production of form lines for color separation plates.

Data from former surveys not yet plotted can be encoded on tape after the fact and processed to smooth sheets directly if range-range control was used during the survey. If not, surveys may be handled by converting observations into range-range coordinates and processed in the same manner.

Automated chart production from a group of surveys is now possible. Computerized methods analyze data and select soundings for plotting based upon previously determined criteria. Depth curves, significant control points, and the projection grid may also be printed out directly by the plotter.

Research Studies—Marine Geology and Geophysics

A vast undersea valley beneath the Andaman Sea was discovered by ESSA scientists using seismic reflection profiling techniques. This valley, 600 miles long and 25 miles wide, is surrounded by submarine mountain peaks. It is presumably a rift valley in many ways similar to the mid-Atlantic ridge system and therefore may be significant in the ultimate solution of the origin of ocean basins.

A previously known, but undescribed, unnamed submarine feature off Miami, Fla., was surveyed and its bathymetry and geology were described. The name "Miami Terrace" was adopted.

The discovery of a new fracture zone in the Pacific Ocean was reported recently by scientists of the IO Marine Geology and Geophysics Laboratory (MGGL). Magnetic profiling was used in a novel manner to reveal the presence of fracture zones undetectable by the usual means. By matching the anomaly patterns on either side of the fracture, it was possible to determine the extent of lateral displacements, which in some cases were as great as 800 km.

Salt domes observed by MGGL scientists in the De Soto Canyon area indicate an extension of major salt trends farther east in the Gulf of Mexico. This is of great interest to the U.S. oil industry, whose major oil reserves in the Gulf area are largely associated with salt structures.

Findings based on reconnaissance work had indicated that a portion of the sea floor off Montague Island, Alaska, underwent violent local upthrusting during the 1964 earthquake. This was confirmed subsequently in FY 67 by MGGL through a series of bathymetric investigations.

The Upper Mantle Project similarly indicated the presence of north-south trending magnetic anomaly bands, first described in 1961. Seismic profiler records confirmed the existence of a basement ridge, presumably granite, at the edge of the Continental Shelf.

A program to measure heat flow through the sea floor has been underway at the Pacific Oceanographic Laboratory during the past 2 years. An instrument system has been developed, and some significant results were obtained in the Upper Mantle Project area off the California coast. In the future, heat flow measurements will be included in geophysical investigations between the Hawaiian and Aleutian Islands. These studies are important, not only to expand knowledge of the earth's crust and mantle but also because heating at the ocean's bottom, if substantial, could produce turbulence and other motions similar to those found at the bottom of the atmosphere, which could be significant in terms of future undersea operations, especially where acoustics are concerned.

Analysis of data from a heat flow investigation off the California coast was undertaken to determine the spatial variability and the extent of regions of high and low heat flow, and to relate these findings to a structural model of the area.

As part of the U.S. effort in the International Upper Mantle Project to complete surveys in the offshore extension of the transcontinental geophysical survey, the ESSA ship *Pioneer* conducted hydrographic, gravitational, magnetic, and seismic reflection profile studies, as well as extensive heat flow and sediment surveys of the ocean bottom off the west coast of the United States.

Past cruises have yielded sediment samples from

various areas. A program has been established to determine particle size distribution in these sediments. The results of these studies will be combined with others to prepare a report on the characteristics of the bottom in this area of the Continental Shelf.

In continuation of a cooperative research program directed toward the study of the processes associated with underwater volcanos, ESSA scientists are supporting the U.S. Geological Survey in a program of bottom photography, dredging, and limited bathymetric studies of the submarine flanks of active volcanos off the Island of Hawaii. This study has produced some significant correlations between the vents in lava beds and the depths of extrusion.

Land and Sea Interaction Studies

In addition to its studies of the benthic boundary, ESSA is also concerned with the boundary between ocean and land at the surface of the ocean—with the interaction that takes place on shores and beaches, and estuaries where rivers enter the sea.

The Mechanics of Shores and Beaches. In cooperation with the University of Southern California, a study of sediment characteristics of the Choptank River in Maryland was completed. This work, which characterized coastal areas highly susceptible to shoreline erosion, suggested the probable cause of erosion and predicted its rate.

The Land and Sea Interaction Laboratory (LASIL) in Norfolk, Va., pursued efforts to develop equations for prediction of the response of beach and near-shore sediments to oceanic and atmospheric forces. Results so far indicate that the approach taken gives a good approximation to the observed behavior of the sediments under typical conditions and should offer a means of predicting beach erosion and deposition, and the velocity of longshore currents.

Estuarine Studies. Although the ODESSA buoy system referred to previously has application to Continental Shelf and deep ocean studies, it was originally developed for estuarine studies by the Joint Oceanographic Research Group (JORG) conducted jointly by ESSA and the University of Washington. In this application, ODESSA buoys are used to obtain information on the general circulation in estuaries and near-shore locales in terms of temperature, salinity, and current speed and direction. The digital data format leads to rapid analysis of results.

Tide Studies. Research on tides is an important facet of the mission of both C&GS and IO. A computer program for editing and reducing data from digital tide gages was completed by the Institute and became operational during the reporting period. This program, together with the conversion of the tide station network to digital gages, will simplify data reduction for C&GS, allowing for automation of a large part of tidal data processing.

ESSA also continued its cooperative effort with the tide research program of the Institute of Geophysics and Planetary Physics of the University of California at San Diego (Scripps Institute of Oceanography), where analysis was made of several long series of tidal data taken by C&GS. As an extension of the studies carried out at Scripps, ESSA researchers developed a new method for predicting tides in shallow water, which, in early tests, markedly improved predictions in two such varied locations as Anchorage, Alaska, and Philadelphia, Pa.

Current Studies. During the reporting period, steps were initiated to improve the tidal current program, including improvements in field procedures, data reduction methods, and presentation of final results. Several Richardson-type current meters were purchased to replace older equipment for measuring the velocity and direction of currents. The new meters do not require monitoring by ships and can record up to 30-day current records. Programs are also available, or are being developed, for computing the nonharmonic reductions required for reversing and rotary currents. These new techniques allow more timely study of tidal current behavior, while at the same time producing more accurate reduced data.

The adaptation of photogrammetric techniques to tidal current surveys now provides for the application of aerial photography to the synoptic measurement of tidal currents at surface and subsurface levels over large bodies of water. The observed photogrammetric data can be reduced for use in the construction of tidal current tables and charts. These surveys, in addition, provide important data for studies on the problem of controlling water pollution, fresh water conservation, sedimentation, shore erosion, and the exploitation of marine resources.

Reasearch and Development—Hydrography and Bathymetry

Activities in this area involve acquisition of new types of data, creation of new types of maps for research purposes, testing and calibration of new types of equipment, and the investigation of photogrammetric techniques for coastal mapping. In most cases, the results of programs are applicable to both hydrography and bathymetry, therefore, no attempt will be made here to separate research and development in terms of relevance to the two fields.

Ocean Surveys. A calibration loop of about 9,000 nautical miles to determine the accuracy of a Navy satellite navigation system was run from San Francisco to Kodiak, Adak, Attu, Midway, Johnston Island, Oahu, and back to San Francisco. Comparisons were made with all standard forms of position determination for reliability, repeatibility, and consistency of fix data.

During the reporting period IO scientists completed a set of six bathymetric maps of the Aleutian Island Arc, extending from south of the Aleutian Trench to north of Bowers Bank, and from the International Date Line to 160° west longitude. These maps represent the first of their kind in the area.

In addition to these research and development surveys, C&GS performed thousands of miles of routine hydrographic and other oceanographic surveys. For example, the *Whiting* completed 1,175 nautical miles of operational cruises, geological profiling, and precision depth recorder soundings.

IO achieved operating economies by collecting its specialized data in conjunction with C&GS basic hydrographic surveys wherever possible. During the recent survey of the northeastern Gulf of Maine, the Institute added special bottom profiling and magnetic profiling instruments to the standard instruments already on board, thus avoiding the necessity for a separate research voyage, and obtaining maximum value from ship operations.

Photogrammetric Mapping. A new photogrammetric activity is now in the development stage to map the mean low-water line of the outer coast of the United States and its possessions for the establishment of coastal base lines for legal and engineering purposes. The use of photogrammetric techniques will permit such mapping to be completed more rapidly and at reduced cost.

THE BOUNDARY BETWEEN AIR AND EARTH

The production of aeronautical charts is a complex, ever-changing challenge. Any change in navigation systems, numbers of aircraft, distribution, type of aircraft, or scheduling produces a multiplicity of new conditions which may affect large, seemingly unrelated sectors of the aircraft traffic network. Since these changes are occurring with increasing frequency, the speedy production of aeronautical charts is a continuing, growing responsibility of ESSA.

Aeronautical Charting

New concepts of chart production and graphic display formats are being developed by C&GS to meet the requirements for aeronautical charting imposed by the phenomenal growth of air traffic and the development of highly sophisticated aircraft navigational systems. The problems of satisfying chart requirements not only consist of meeting current needs but also must include chart development to satisfy flight requirements in the future navigational complex. The program is divided into three categories: (1) development of new production techniques and concepts, (2) development of new graphic displays, and (3) studies of present operating methods and systems used to produce nautical and aeronautical charts.

Operating Methods and Systems Studies

Studies to obtain storage of a body of knowledge on navigational systems are continuing, particularly those having possible application to navigation of supersonic transports.

Automatic data processing was introduced into the handling of aeronautical data for the production and revision of aeronautical charts previously processed by means of manual posting, filing, and dissemination.

Development of New Production Techniques and Concepts

An urgent requirement existed during the reporting period to produce two prototype charts for evaluation by the Inter-Agency Air Cartographic Committee (IACC) and, subsequently, two production charts in conformance with newly developed joint specifications. Consequently, production methods and procedures were adapted to: (1) test various screen angles and determine printing specifications which satisfy both IACC and C&GS requirements; (2) develop a method to produce 120-line production copies from 133-line half-tone screens; (3) devise methods to adapt existing relief originals to conform to terrain display requirements for three prototype study charts. The concept of a new terrain portrayal was further developed and two prototype charts were printed, under controlled conditions, by the color process printing method.

A photomechanical method of producing vignettes has been further refined so that the operation now has been reduced to a single half-tone exposure, entailing a substantial reduction in time and man-hours from the cost of the original vignette process.

New materials and techniques have been tested and evaluated for possible application in the production of charts, the most significant of which is the new Duplication Scribecote, which represents a significant breakthrough in reproduction processing. With this process, it will be possible to make a negative from a negative on a stable material which permits corrections and, at the same time, reproduction. Should all expectations for this product be realized, the project to convert remaining glass negatives to film will be accelerated.

Development of New Graphic Displays

Developmental work in graphic display has resulted in the construction of three prototype charts with unique format characteristics. Some primary objectives of these efforts are the elimination of contours which cause an excessive amount of clutter, the use of softer tones to alleviate conflict of data, combining the best properties of shaded relief and tint systems, and determination of the relative merits of pictorial and geometric symbolization in an effort to present the best data display to pilots. These prototypes are documented and will be evaluated, along with others now being planned.

THE BEHAVIOR OF THE OCEANS AND ATMOSPHERE

The atmosphere and ocean are two elements in a complex system. Interactions weave air and sea together, driving ocean waves and major currents, distributing solar energy, generating and sustaining marine and atmospheric hazards, and determining long-term and transient variations in climate.

Ocean and Atmosphere Structure and Dynamics

This topic involves the description of the dynamic behavior of the ocean and atmosphere, and the interactions between the two fluid media. Disciplines included are physical oceanography, climatology, atmospheric physics and chemistry, and the mathematical modeling of the ocean and atmosphere. Research programs in

this area have a direct relation to ESSA's service missions, supporting programs in weather forecasting and warning, and river and flood prediction.

Facilities for Research and Development

In addition to the ESSA fleet of oceanographic ships, there are several major shore-based facilities for research in physical oceanography—in some cases, the same facilities used in other portions of the overall ESSA program in oceanography. The IO facilities involved include: The Physical Oceanography Laboratory and the Sea-Air Interaction Laboratory at Miami, Fla., and the Pacific Oceanographic Laboratory and the Joint Oceanographic Research Group with the University of Washington at Seattle, Wash. Ship and other facility support is provided to the program by C&GS through its Atlantic and Pacific Marine Centers at Norfolk, Va., and Seattle, Wash., respectively.

Portions of the program, particularly those involved in the study of sea-air interaction, require instrumented aircraft, which are furnished as needed to support programs by ESSA's Research Flight Facility (RFF), located at Miami, Fla. Increasing use is being made of satellite data in the study of oceanography, and facilities are available for satellite data acquisition at the National Environmental Satellite Center (NESC), at Suitland, Md., and its command and data acquisition stations at Gilmore Creek, Alaska, and Wallops Island, Va.

The Institute for Atmospheric Sciences (IAS) plays a major role in this area of research and provides facilities for its Atmospheric Physics and Chemistry Laboratory at Boulder, Colo., and the Geophysical Fluid Dynamics Laboratory in Washington, D.C. This latter facility is equipped with high-speed computers for experiments in modeling the oceans and atmosphere and their interaction. The Environmental Data Service performs research in climatology, in addition to its service functions in this field, and maintains facilities for this purpose in Silver Spring, Md., at the National Weather Records Center at Asheville, N.C., and, in cooperation with the University of Nevada, at Reno.

Instrument and Systems Development

Although individual laboratories contract for the development of special purpose instrumentation from time to time, most development of oceanographic equipment is performed by the Engineering Division of C&GS at Rockville, Md. Similarly, in the case of atmospheric research instrumentation, most development is performed by the Equipment Development Laboratory of the Weather Bureau, with contributions from other elements of ESSA, notably ITSA. Highlights of the instrument and systems development program in this area follow:

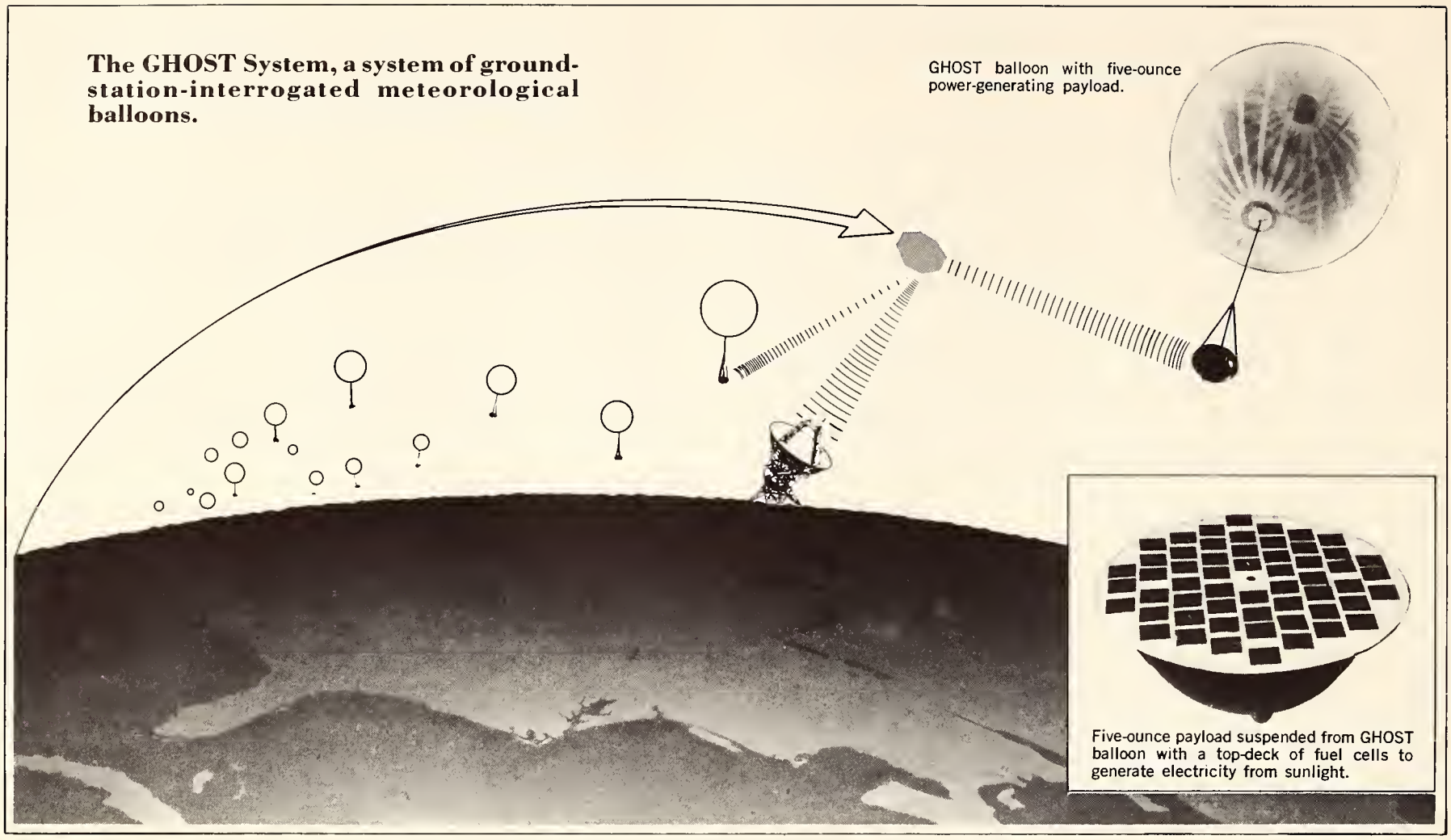
Deep-Sea Tide Gage. A number of advances have taken place in the technology of measuring tides in the deep sea. Earlier deep-sea tide gages, which were able to measure tides in water 840 feet deep, have been redesigned for operation in water up to 5,000 feet deep. Preliminary tests of these gages have been completed and field operations will commence in FY 68. A gage of the same type has also been used on the underwater stable platform, developed originally to take magnetic measurements, to measure tides successfully in water at a depth of 4,200 feet.

Measurement of Ocean Parameters. An electronic salinity, temperature, and depth sensing system developed by the Pacific Oceanographic Laboratory of IO has been used successfully to produce data on the ocean microstructure.

Measurement of Winds Aloft at Sea. It is difficult to make observations of winds aloft at sea using conventional rawinsonde techniques because of the rolling and pitching of a surface vessel. Because the accuracy required is high (.25° up to a distance of 50 miles horizontally and 20 miles vertically), efforts have been underway to develop a means of compensation for ship motion. Substantial progress toward this objective was made during the reporting period with the completion of a gyro-stabilized azimuthal direction-finding antenna, using a sensing system known as a Wullenweber array. This array can track a radiosonde signal through 360° at a rate of 12° per second; data on azimuth is presented both as a direct readout and as a continuous analog recording of the angle. The Wullenweber array was tested on a shipboard simulator, developed by the Weather Bureau's Test and Evaluation Laboratory, before undergoing actual sea tests and then tested close to shore so that comparisons could be made with land-based observations.

Satellite Interrogated Balloons. In order to obtain meteorological data aloft on a global basis, a system has been proposed involving the use of a large number of instrumented constant-level balloons to be interrogated by satellite in the same manner as meteorological buoys. This system, labeled the Global Horizontal Sounding Technique (GHOST), underwent pilot test using data acquisition by ground stations in a joint United States–New Zealand program during FY 66 at Christchurch, New Zealand. The program is managed by the National Center for Atmospheric Research and is sponsored jointly by ESSA and the National Science Foundation (NSF) with the endorsement of the World Meteorological Organization (WMO). Technical coordination for ESSA is the responsibility of the National Environmental Satellite Center.

Instruments on the balloons sense temperature and pressure at a constant pressure altitude and transmit the information to ground stations (or to satellites later). Each balloon identifies itself so that a plot of its succeeding position can give winds aloft at the balloon altitude. Results of the test program have been generally successful at altitudes of 40,000 feet and higher. At lower altitudes, moisture and icing have caused problems which are presently under study. The pilot project has involved a total of 50 balloons to date. An operational GHOST System would involve upwards of 10,000 balloons, and would have to solve problems of potential interference



with air traffic, but the concept does appear to offer at least one means of obtaining the type of global synoptic data which will be needed for future environmental prediction systems.

Research in Physical Oceanography

The oceans of the world are never static, but remain in constant motion in response to the influences of wind, tides, and the boundary with the solid earth. ESSA's Open Ocean Tide Program is planned to comprise the principle part of the U.S. contribution to the International Deep Sea Tide Program of the International Association of Physical Oceanography.

Deep Ocean Tide Studies. ESSA has embarked on a program to observe tides systematically throughout the earth's oceans. In the past, tidal measurements have been restricted to coastlines and isolated islands because of instrument and logistic difficulties involved in recording open-sea measurements. However, because of advances in instrumentation, platforms, and data processing systems, such measurements have become feasible.

ESSA's observation of tidal propagation is centered on the following objectives:

- □ Understanding tidal propagation mechanisms,
- □ Obtaining data for input to dynamic-numerical prediction models,
- □ Determining the magnitude of tidal friction,
- □ Corrections to gravitational and magnetic fields for the effects of global tides,
- □ Correcting soundings in the open ocean,
- □ Predicting open ocean tides,
- □ Obtaining information for geodetic leveling, and
- □ Supporting the tsunami warning system.

Current Studies. In addition to obtaining data on nearshore and estuarine tidal currents, ESSA is vitally concerned with offshore and open ocean current studies.

Part of a multi-ship, multi-organization endeavor to study the Gulf Stream comprehensively was begun in August 1965 by the *Explorer* and *Peirce* and completed in April 1967. The ships surveyed along the 15-degree isotherm (line of constant temperature) from Cape Hatteras to a point south of Nova Scotia. Data were taken monthly over the course to ascertain if there was a cyclic pattern to changes in the Gulf Stream meanders during a 1-year period. The *Peirce* operated on a biweekly basis, observing a standard cross-section of oceanographic stations on a line perpendicular to the Gulf Stream axis. This investigation obtained the longest sequence of observations of Gulf Stream meanders ever made, and a year-long series of fortnightly profiles across the stream off South Carolina. In addition, a new field operation—an investigation of the flow between the Western Atlantic and the Caribbean through the Anegada Passage—was successfully conducted.

ESSA also conducted a number of projects in Pacific physical oceanography emphasizing large-scale phenomena, including systems within the Pacific, seasonal and annual changes in properties and currents, and long-range meteorological-oceanographic energy exchange. Studies in microstructure and short-term variability are

pursued primarily in the interest of establishing process rates and mechanisms and relevancy of measurements.

In FY 67, the backlog of time series data acquired by C&GS on the SEAMAP surveys were processed through the National Oceanographic Data Center (NODC), and studied for annual variability of currents and mass transport. Based on a field investigation off the California coast in February 1966, a technical memorandum (POL Tech. Memo. No. 3) was published. It reported on a comparison of an *in situ* sensing, electronic instrument system (STD) with a conventional Nansen cast technique. The report concluded that the results of the electronic system, when expressed as geostrophic currents, were at least equal to the older method, and in addition revealed significant microstructure otherwise undetected. The time history of an anomalous water parcel detected by STD was described over a period of a few hours.

A study of abyssal waters in the Central North Pacific was concluded through its initial stage, utilizing a special method for screening data, based on the SEAMAP stations of 1961 through 1966. It is evident that anomalous "young" water reaches the vicinity of the Aleutian Trench by some unknown route other than directly from the south.

A new echo-sounding correction technique provides for computerized correction of soundings with a precision previously not available. The new basic data upon which the procedure is based shows a higher speed of sound in most cases than the Matthews Table, indicating ocean depths will be found to be slightly deeper.

Ocean Studies by Remote Sensors. Studies are underway to develop a capability for using remote oceanographic sensors from aircraft and satellites. Although primary attention is being given to infrared techniques for measuring surface temperature, other methods, including color photography, radar scatterometry, and microwave radiometry, are being considered. For *in situ* studies, a self-recording tide and wave gage system was placed on top of the Cobb Seamount, 270 miles off the Washington coast. The environmental information to be derived from this system is essential to proposed efforts to establish a service and research station on Cobb Seamount.

Satellite Studies of Sea Ice. Although large masses of sea ice are identified by satellite sensors today and information on its location is made available to mariners through the Coast Guard, individual icebergs, except for large types, are beyond the resolution of present operational satellite sensors. Studies are underway in conjunction with other Federal agencies to evaluate the feasibility of iceberg detection using improved sensors aboard larger satellite vehicles which should become available in the future.

Sea and Air Interaction Studies

While several different organizational elements of ESSA are concerned with this interface in one way or another, the Sea-Air Interaction Laboratory (SAIL) of IO has the primary responsibility of maintaining cognizance of all aspects of research in this area and developing a theoretical basis for improved marine environmental predictions.

Storm Surge. Offshore storms may interact with the sea in such a way as to produce abnormally high or low tides which may present a hazard to coastal areas. This phenomenon, known as *storm surge* is not at present fully understood, and is therefore not yet subject to accurate prediction.

ESSA's research effort to describe and understand storm surge is theoretical as well as observational in nature, and involves numerical analysis of shallow water wave equations to determine the response of the sea to the driving forces of atmospheric storms. The present model is somewhat simplified. It describes storms with a restricted number of physical parameters amenable to observation, such as the pressure drop in a storm. The coastline is simulated by a rectangular basin open to the sea on three sides and having the width of the Continental Shelf.

Results to date show that bottom stress (the force due to exchange of momentum between the water and the bottom surface) is only of minor concern for fast moving storms crossing the coast at not too acute an angle. However, for all other storm motions, bottom stress has a commanding effect. A series of computations has been completed, assuming a linear bottom stress in the equa-

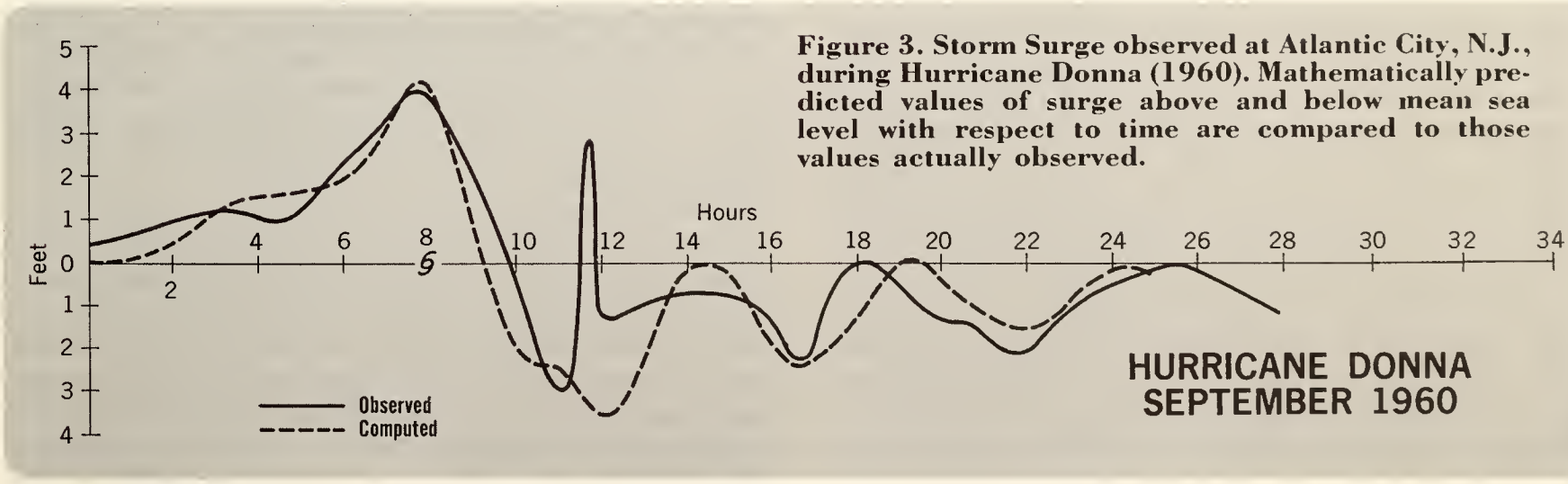


Figure 3. Storm Surge observed at Atlantic City, N.J., during Hurricane Donna (1960). Mathematically predicted values of surge above and below mean sea level with respect to time are compared to those values actually observed.

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tions of motion, that considers storms traveling in any direction and speed relative to a straight-line coast, including storms not making landfall. The results of these computations have been incorporated in nomograms and give a preliminary objective forecasting scheme for storm surge under certain conditions. Application of the nomograms to the storm surge produced at Atlantic City by Hurricane DONNA gave the results shown in Figure 3.

Basic research is continuing on the problems of incorporating curvilinear coastlines into a numerical model. A detailed mathematical analysis of nonlinear effects in shallow water waves on beaches has been completed and a report is being prepared. The behavior of the numerical schemes developed to date is good with regard to waves traveling normally to the shoreline, but requires further development for waves traveling in the longshore direction.

Experiments with curvilinear boundaries demonstrate that considerable care must be given to finite-difference conservation laws in order to avoid wild growth instabilities in the computer solutions.

Wind-Generated Waves. The interaction between sea and air through the formation of wind-generated waves is an important facet of SAIL study. A program to study wave formation under various meteorological conditions on the Great Lakes has been initiated. This "wave climatology" study, based on historical data as well as current observation, in addition to providing basic input to future air-sea interaction studies should aid materially in the design of future Great Lakes ships and the maximum utilization of the present fleet.

Data obtained by the University of Michigan under ESSA sponsorship show several systematic deviations between the air flow observed over waves and that predicted by theories widely held until recently. This group and others are continuing the study of wave formation in an effort to produce improved theories.

ESSA members of the Joint Oceanographic Research Group (JORG), in conjunction with the University of Washington program in physical oceanography, initiated two investigations of wind effects on tides, during the reporting period. The first, in the Dabob Bay–Hood Canal area, involved collecting field data from three tide gages and associated wind records, during the period December 1965–February 1966. Reduction of the tide data has been completed, and the analysis of wind records started. The second study involves similar data from a tide gage installed by JORG at Port Gamble, Wash. Data from this tide gage will be used in conjunction with a program of environmental measurements conducted from July through October 1966 from the Hood Canal Bridge by the University's Department of Oceanography.

Heat and Water Vapor Exchange. The exchange of energy at the boundary between sea and air in the form of heat and energy of vaporization is a major topic of investigation since these processes are the source of energy for hurricanes and other ocean storms. Primary effort during the reporting period centered on sensor development and the search for an adequate theoretical model to interpret observational data.

An infrared radiometer capable of accurately measuring sea surface temperature from an aircraft is essential, since such a device in conjunction with expendable bathythermographs will be the principal source of data for computing oceanic heat budgets. Because existing equipment was not sufficiently stable or suited for unattended operation for any period of time, a new self-calibrating, drift-free radiometer has been developed which operates in a region of the spectrum relatively unaffected by water vapor absorption.

In a further effort to determine the effects of water vapor absorption on infrared radiation, and provide a means for correcting observations to obtain more accurate sea surface temperature readings, a program is underway in conjunction with the University of Wisconsin. A computer program will be developed to give the error to be expected from water vapor absorption when only the surface temperature of the sea is known.

In spite of the fact that existing equipment is unsatisfactory from a number of points of view, some useful data were obtained from aircraft infrared observations during the reporting period. The effects of Hurricane BETSY on the surface temperature pattern of the Gulf of Mexico were successfully mapped and results agreed well with observations made from surface vessels.

Boundary Layer Studies. Techniques are being developed to investigate the structure of the atmospheric planetary boundary layer over the oceans. Radiosondes operating on the 403 mc band have been modified and flown over the ocean from tethered kytoons or parafoils. Humidity fluctuations at various levels over the water from 1 meter up to 125 meters have been recorded. Various instrumental improvements are underway and the system will ultimately measure temperature, pressure, humidity, and horizontal wind velocities in the boundary layer.

Atmospheric Physics and Chemistry

Understanding atmospheric dynamic behavior requires a knowledge of the physical and chemical processes associated with weather phenomena. ESSA's effort in atmospheric physics and chemistry has as its specific objectives to increase understanding of the atmospheric physical processes related to clouds and precipitation, and to evaluate the chemical composition of the atmosphere, including such constituents as ozone, carbon dioxide, and cloud and precipitation nucleating substances.

Atmospheric Physics. The study of the particulate matter suspended in the earth's envelope is of paramount importance to *cloud physics* and air pollution. Atmospheric particles are grouped according to the supersaturation level at which they become nuclei for cloud droplets. For example, *Aitken nuclei* are those particles activated by supersaturations ranging from 100 to 3,000 percent in an Aitken dust counter. They are of significance in measuring

atmospheric pollution and play an important role in atmospheric electricity, but they do not in general contribute to natural cloud formation. *Cloud nuclei*, on the other hand, which are those particles of primary importance to natural cloud formation, are active at low supersaturations, seldom rising above 0.1 percent.

During the reporting period, research was undertaken to determine the natural processes by which cloud nuclei are generated and released into the air from the earth's surface. The results suggest these nuclei are in part released during the rupturing of water solution membranes in the soil interstices when the soil dries out. Other research showed that atmospheric stability is important in determining the average Aitken nuclei concentration at the earth's surface, and, therefore, in determining the degree of atmospheric pollution.

In the field of atmospheric electricity, the Laboratory completed the analysis of a 1-year record of atmospheric electricity at the relatively pollution-free ESSA High Altitude Observatory at Mauna Loa, Hawaii. Results indicate that the level of the atmospheric electric field is significantly affected by the occurrence of solar flares, and lead to further speculation regarding the interaction mechanism between solar events and weather.

Atmospheric Chemistry. ESSA's program in atmospheric chemistry has continued to concentrate on the study of ozone and other atmospheric constituents. There are now 16 ozone observation stations including a new station at Boulder, Colo., added to the network in 1967. Except for limited observations conducted at Amundsen–Scott and Byrd stations, Antarctica, the large ozone vertical distribution measurements program operated during the International Year of the Quiet Sun has been curtailed pending completion of data analysis.

Other activities during the reporting period have involved the development and testing of new instrumentation for sensing ozone and other atmospheric constituents. An important area of interest is the monitoring of carbon dioxide and oxygen content in the atmosphere, since there is some indication that a potentially dangerous change may be taking place in the balance between these two constituents in the atmosphere. A carbon dioxide monitoring facility will be established at Boulder, which will also serve as a laboratory for the analysis of samples taken at other locations. Changes will be observed both as a function of time and as a function of location.

Modeling of the Ocean and Atmosphere

While it is necessary to study experimentally both the large-scale behavior of the earth's fluid media and the details of their physics and chemistry in order to gain understanding of the processes involved, it is equally important that mathematical tools be developed which can model both large- and small-scale processes, in order that the data obtained can be used effectively for prediction, warning, and/or modification. The Geophysical Fluid Dynamics Laboratory (GFDL) of IAS has primary responsibility for this phase of research in ESSA. These investigations also support, to an extent, the National Meteorological Center's program to develop computer means of real-time ocean and atmosphere prediction.

Largely, but not exclusively, GFDL's studies involve the formulation of theoretical models of the atmosphere and oceans, the properties and behavior of which are studied in detail through numerical integration of the model equations on a digital computer. The program falls into three main categories: theoretical studies, experimental prediction, and observational studies.

Theoretical Studies. Calculations with a 6-level *ocean circulation* model have been extended to a highly nonlinear range of basic parameters. Intensive effort has been devoted to analyzing the basic physics revealed by the solutions, and verifying the mathematical accuracy obtained. This is an essential preliminary step to further application of the numerical ocean model to ocean-atmosphere interaction studies.

In the study, the temperature pattern given by the model is compared to the observed temperature at a depth of 200 meters. The calculated pattern indicates the formation of an extensive warm pool of water near the western boundary, as well as the effects of upwelling along the eastern coast in low latitudes. The effects of cold-water advection associated with the equivalent of a Labrador current is also evident along the western boundary at higher latitudes. There is a defect in the solutions due to lack of a sharp thermal front along the northern edge of the warm pool. It is believed that this feature will appear in more detailed calculations with lower turbulent viscosity and a finer numerical grid.

Study was made of vertical cross sections along an east-west line. The calculated density field was compared with data taken during the International Geophysical Year by the Woods Hole Oceanographic Institution. A graded net has been used in the computation to resolve the very fine thermal and velocity structure at the western boundary. The gentle slope upward to the east of surfaces of constant density is shown in the calculations to be directly due to the wind stress pattern. It appears to be impossible to explain this feature in terms of an ocean circulation driven by thermal forces alone.

A comprehensive calculation of the wind stress at the ocean surface based on actual data for all seasons has been completed. This is part of the preparation for general circulation calculations in which actual boundary conditions of the world will be duplicated as closely as possible.

The major objectives in studying the *general circulation* of the atmosphere are to simulate numerically the climatology and the general circulation of the atmosphere involving the minimum number of parameters necessary to provide good modeling, and to gain a coherent understanding of the mechanism which maintains the structure of the atmosphere. In carrying out experiments in this field, various checks are made, including experimental forecasting to determine the dependability of the model,

and computer runs where different variables are omitted to determine their importance to the model.

A detailed analysis of the general circulation of the moist *tropical model atmosphere* has been completed. Results are generally in accord with observation, showing, for example, a belt of intense rainfall in the model tropics, synoptic scale disturbances, maintenance of kinetic energy in these tropical disturbances through the release of latent heat of vaporization, and vertical temperature distributions similar to those observed in the real atmosphere.

Ocean-atmosphere coupling is one of the most important factors in determining the long-range evolution of climate. A scheme for incorporating these effects has been worked out. Before combining the atmospheric model with the ocean model, it is necessary to incorporate the effect of surface hydrology into the atmospheric model. A simplified system of predicting snow cover, soil moisture, and runoff has been formulated, and the computer program for its execution has already been completed. As a preliminary phase of this project, the numerical integration of the atmospheric general circulation model with surface hydrology is in progress.

The model techniques developed to simulate the long-term behavior of atmospheric general circulation have been extended to deal with the general circulation of the oceans, and recently, have been applied to the total fluid envelope of the earth, ocean, and atmosphere, as a single physical system.

An improved version of the time integration of the hydrodynamic equations on the new global grid system has been formulated and tested at low grid resolution. The resolution has been increased, and a new definitive test of the scheme using a model without the hydrologic cycle has been started. Following conversion of this program to the Univac 1108, and the completion of studies, such as those involving the addition of *radiative heat transfer* to the model and those involving the effects of the photochemistry of *ozone*, the other processes will be added to the model one by one until a completely general model of global weather will be available.

Other theoretical studies during the reporting period included those dealing with penetrative convective instabilities, barotropic stability theory and tropical disturbances, and numerical convection experiments.

Experimental Prediction. The real data studies of GFDL's program in experimental prediction are centered on eight problems:

1. Determination of initial conditions,
2. Hemispheric forecasts which include the effects of radiation and land-sea contrast,
3. Diagnostic studies of southern hemispheric and tropical circulation,
4. Sudden warming in the stratosphere,
5. Precipitation,
6. Fine resolution grid forecasts (80 grid points between the equator and the North Pole),
7. Tropical forecasts, and
8. Global forecasts.

Progress in these areas is briefly summarized in the following paragraphs.

The conventional scheme for *determining initial conditions* has been coded for the CDC 6600 and is in use. A new technique studied during FY 66 was promising, but had minor defects and required excessive computation time.

A 4-day *hemispheric forecast* was conducted using past data, including the effects of radiation and land-sea contrast, with mixed results. Although the prediction of cyclones and tropical condensation rates was improved, discrepancies in coastal temperatures developed which should be reduced as the model is refined.

During FY 67, GFDL performed several experimental 2-week predictions. Experiment 1 had no radiative transfer and no turbulent exchange of heat and moisture with the lower boundary. Experiment 2 included the effects excluded in Experiment 1 plus a land and sea contrast. Experiment 3 contained all the features of Experiment 2 plus a thermal property difference between land and sea ice surfaces and a condensation criterion set at a relative humidity value of 80 percent in contrast to 100 percent in Experiments 1 and 2.

The study has led to a number of important conclusions:

a. Two-week forecasts, on the basis of this sample, show considerable skill and the feeling exists that this skill will be improved in the future.

b. The model succeeded in forecasting the formation of second and third generation cyclones and their subsequent behavior.

c. The generally accepted idea that forecasts are greatly improved by considering sea surface temperatures was reconfirmed.

d. It is necessary to take into consideration the thermal difference between sea-ice and land-ice surfaces in order to obtain a proper value for the temperature at lower levels in high latitudes.

Observational Studies. The dissipation of kinetic energy is one of the fundamental processes in the atmospheric energy cycle. Although critically important to the development of general circulation theory, this process has been comparatively unstudied because of the complex nature of the mechanisms and the difficulties in finding a practical approach. Therefore, the Geophysical Fluid Dynamics Laboratory (GFDL) is engaged in a comprehensive study of the kinetic energy balance in relation to generation and dissipation processes, using Northern Hemisphere daily aerological (wind and geopotential surface) data. The use of aerological data and a carefully designed scheme of analysis relieves the study from some of the major constraints from previous approaches, and the results thus far obtained are promising.

In view of the initial success of the method, actions for FY 67 included: Extension of the data area from North America to other parts of the Northern Hemisphere, including direct study over continental areas and indirect study over ocean areas; use of a large data sample for an extended period (5 years is proposed); and a study of dissipation by different mechanisms, and its incorporation into mathematical models of atmospheric circulation.

Climatology

One of the key inputs in developing mathematical models of the atmosphere is climatological data gathered over an extended period of time. Research in climatology is conducted by the Environmental Data Service (EDS) in the categories of climatic change, synoptic climatology, severe storm climatology, bioclimatology, urban climatology, and three-dimensional global climatology.

Climatic Change. Research in climatic changes focuses largely on historical climatic change and its cause, but is also concerned with the expansion of the Climatic Reference Station Program, designed to provide climatic reference points in areas relatively undisturbed by human influence.

During the reporting period, a study was initiated to determine more precisely how representative the envisaged Reference Climatological Network will be in specifying climatic change throughout the conterminous United States. New instruments were tested for installation at 17 reference stations.

In a parallel effort, an analysis of mean temperature and total precipitation changes in the period 1931–65 was initiated to compare data averaged over a region with data from individual stations as indices of change, and to study in detail the pattern of climatic fluctuation in the country during the past 35 years.

Meanwhile, the possibility that long-term changes of solar activity are a contributory cause of climatic change was examined from several points of view. An investigation of possible solar influence on climate was continued by means of cross-spectral analysis between sunspot series and historical temperature and tree-ring series. Although results of this analysis have failed to reveal a consistently significant relationship, they are highly suggestive of a weak relationship with the 11-year sunspot cycle, and of a somewhat stronger relationship with longer period variations of solar activity, such as the 80–90 year cycle.

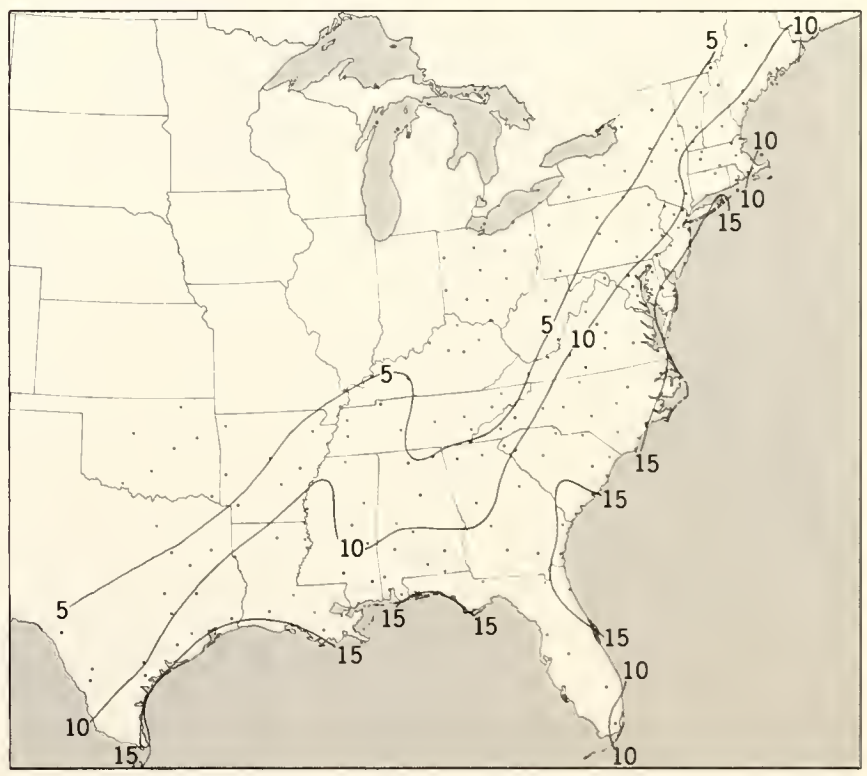
The potential role of air-sea interactions in causing climatic change was further examined by means of two numerical models describing the time history of heat exchanges in the ocean and atmosphere as a thermally coupled system. One model is capable of describing relatively rapid climatic fluctuations possessing many of the statistical characteristics of inter-annual climatic changes actually observed during the past century. The other model leads to long-term fluctuations of climate that are believed to have a bearing on the chronology of the Pleistocene Ice Age.

Synoptic Climatology. Research in synoptic climatology, during the reporting period, centered on the Arctic region. The study of the climatology and meteorology of Greenland was concluded with the investigation of upper winds over Greenland and the surrounding area, and with a mesoclimatic investigation of the Greenland ice sheet western slope.

Investigation of climatic conditions in Alaska continued during the reporting period on the following problems:

1. Basic weather patterns, day by day, for the period of January 1, 1945, to March 31, 1963;
2. The analysis of extreme cold winters in Alaska;
3. The computations of mean monthly heights of the 500 millibar pressure level, and mean monthly thicknesses of the layer between 500 and 1,000 millibars, as well as the variations of these elements from month to month and from year to year;
4. The computations of height, temperature, and pressure at tropopause level according to three upper air stations; and
5. The evaluation of surface inversion according to daily records of three Alaskan upper air stations.

Severe Storm Climatology. A study of the contribution of tropical cyclone rainfall to the distribution of precipitation in the eastern and southern United States was completed during the reporting period. Results showed that although 10 percent or more of all precipitation during the months of June through October (1931–60) was associated with tropical cyclones, most cyclones occurred during normally wet periods. As a result, very few periods of established drought were ended through rainfall associated with such tropical cyclones.



Tropical cyclone precipitation shown as percentage of total precipitation, June–October 1931–60.

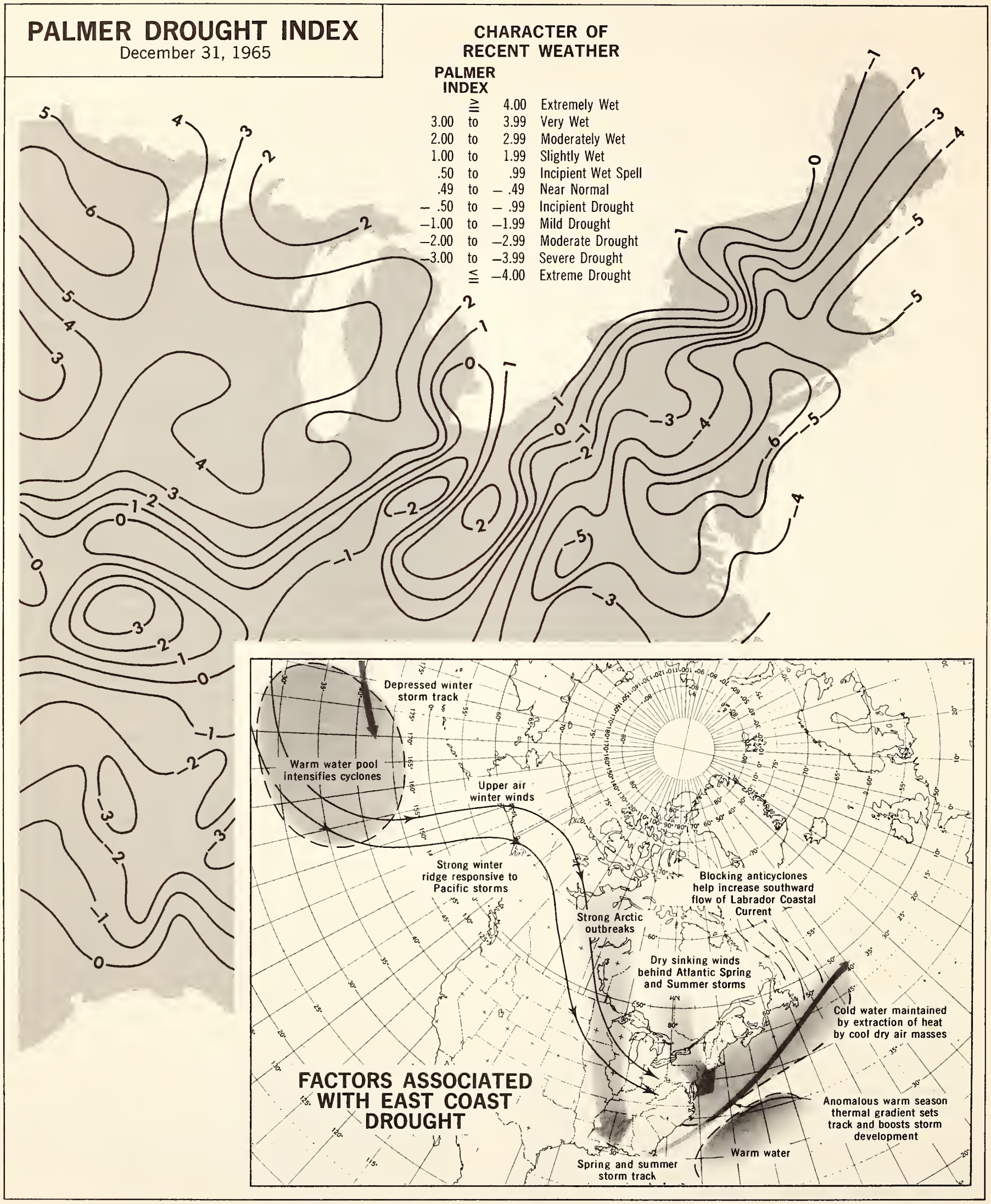


Figure 4. Drought severity map, an index of the character of the moisture aspect of recent weather.

Bioclimatology. ESSA's program in bioclimatology is primarily concerned with drought and its effects. Climate governs the water income as precipitation; it controls the losses from soil and open water surfaces. Crops depend on adequate water supply, and modern communities and industries cannot function without it. Knowledge of the climatological probabilities and risks of water deficiencies and excesses is necessary for effective planning in water resources management.

A machine procedure has been developed for determining the extent and severity of periods of unusually wet or dry weather for various areas. This procedure has been applied to the historical record of weather and climate since 1930, and drought severity expectancies have been calculated for most areas of the United States. For example, Figure 4 is a map prepared by the National Weather Records Center, using this procedure, which shows the recent extreme drought condition in the Northeast. Water shortage problems, caused almost entirely by unusual and persistent drought, have afflicted this highly developed region since the fall of 1961. Municipal and industrial water shortages were most prominent and most publicized; but agriculture, the dairy industry in particular, did not escape economic losses due to this drought. It should be helpful for water management authorities in this area to know that, based on past weather records, drought of this duration should only be expected to occur once in about 150 years.

Urban Climatology. ESSA has embarked on a cooperative project with a number of other Federal agencies in the development of climatological observational networks and the interpretation of existing and anticipated data from the Nation's growing urban industrial centers. During FY 67, for example, EDS scientists took illumination measurements from urban areas in an attempt to derive a relationship between pollutant concentration and sunlight. EDS also related urban weather records to rural weather records to separate the effects of preexisting climate in a region from the climate produced by the urban area itself. These data are related to long-term existing records as possible inputs in city and urban planning.

Three-Dimensional Global Climatology. A variety of studies were conducted in this field. For example, a considerable effort has been made to assess the point-to-point variability of meteorological parameters, in order to provide a basis for determining the optimum spacing of observation stations. For surface variables the optimum distance between stations in hilly or mountainous terrain is about 25 miles. For upper air temperatures an optimum distance is 50 miles. For upper air winds an optimum distance is 250 miles. Beyond these distances, significantly different distributions are to be expected. These distances may be increased if the user will accept a greater deviation of weather from the norm over the region of interest.

Determination of the transport of water vapor in global circulation has been difficult because, in general, moisture information is only obtained from precipitation data taken at the surface at various places and times. However, making use of the daily record of upper atmospheric temperature, pressure, humidity, and wind data from rawinsondes over the United States stored at the National Weather Records Center in Asheville, N.C., EDS scientists have prepared maps showing mean zonal transport of water vapor on monthly basis.

Other studies during the reporting period covered such topics as: Estimates of winds at intermediate heights generated from winds recorded at constant pressure surfaces, the uses of some statistics in meteorology and climatology, the spectrum of angular momentum transfer in the atmosphere, and a study of means to eliminate erroneous data from homogeneous bivariate distributions.

THE UPPER ATMOSPHERE AND SPACE

Because of the importance of the ionosphere in radio communications, very high levels of the atmosphere have been the subject of extensive measurement and study. Forecasts of ionospheric conditions in support of communications have been made for many years.

With the advent of space exploration, the regions beyond the atmosphere have come under intensive investigation. Research into the characteristics of both regions has become an important aspect of ESSA's science and engineering program.

Aeronomy

The study and description of the physical, chemical, and electrical properties of the "upper" atmosphere constitutes a relatively new scientific field called aeronomy (the word aeronomy was invented in 1945). It is not possible to specify exactly either the lower or the upper limits of the region of the atmosphere constituting the domain of aeronomy, but about 40 km. (just above the ozone layer) may be taken as a convenient lower boundary, and 70,000–80,000 km. (the approximate outer edge of the earth's effective magnetic field) for the upper boundary. This domain begins where the atmospheric density is reduced to 0.0003 of that at sea level and ends where the distinction between the upper atmosphere and interplanetary space is trivial. Studies in aeronomy include direct measurements from rockets and satellites, indirect measurements of the upper atmosphere from ground stations, simulation of atmospheric conditions in laboratory experiments, and the synthesis of these observational and experimental data by theoretical evaluations.

The results of these studies are important, both from the point of view of telecommunications and of astronautics, in providing information on which future systems designs and operational plans may be based. This portion of ESSA's program to describe and understand the environment is carried forward by the Aeronomy Laboratory of ITSA.

The Structure of the Lower Ionosphere

Paradoxically, the lowest region of interest to aeronomy is the most difficult to study. At altitudes above about 175 km., satellites can remain in orbit long enough

to obtain meaningful quantities of direct observational data, but below that altitude, it is presently not feasible to fly satellites; and of course, the altitude is well above the reach of balloons. Until better methods of acquiring direct data can be devised, scientists are forced to be satisfied with indirect measurements from the ground, for the most part, with only infrequent sounding rocket flights to provide brief direct observation. Although six such rocket experiments were carried out by ESSA personnel during the reporting period with useful results, the largest amount of data was obtained from radio soundings and observations of aurora and noctilucent clouds.

The region from about 90 km. up to the point of maximum electron density in the atmosphere (ranging from 250–400 km.) is directly accessible to measurement by ground-based radio sounding. Although the electrons and their accompanying ions represent only a "trace element" throughout this part of the neutral atmosphere, they are particularly important, through their strong interaction with radio waves, for practical long-distance communication and as a sensitive indicator of the physical state of the upper atmosphere. Several high frequency radio techniques are used to observe the structure, time variation, and movement of the ionosphere.

In ground-based studies of the ionosphere, ITSA scientists designed a new experimental program for radio measurement of ionospheric motions throughout the ionosphere, including vertical component drifts, during FY 67. A six-frequency digital sounding system and new least-squares method of data analysis were also developed and tested during experiments at Yuma, Ariz.

In the two sweep-frequency soundings of the ionosphere in Figure 5, the horizontal frequency scale may be interpreted directly to determine the electron concentration at the altitude at which the echo pulses were reflected. The *apparent height* of reflection (vertical axis) is related in a complex manner to the real height, but such

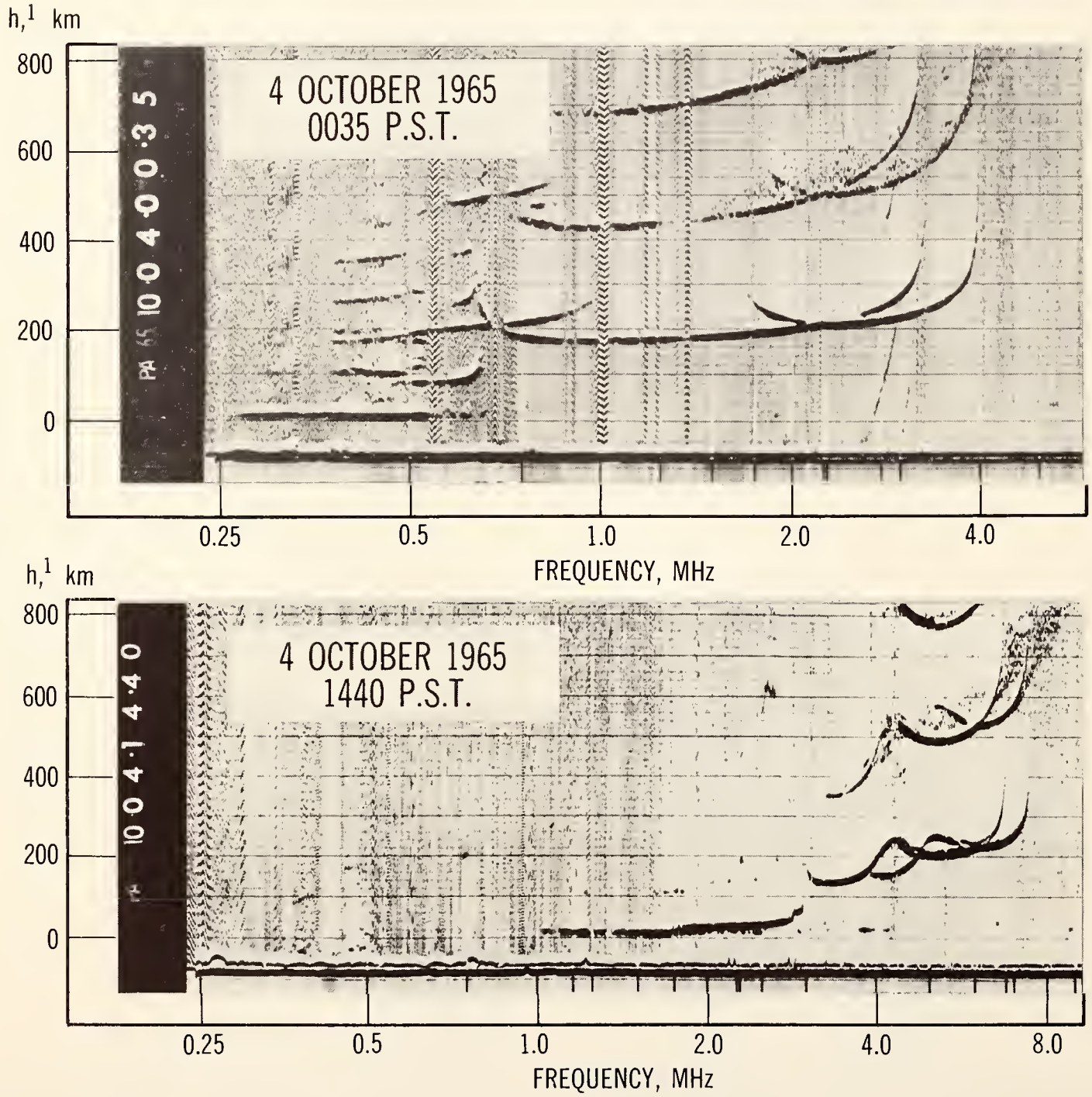


Figure 5. Typical ionograms, model J. Ionosonde, Point Arguello, Calif.

ionograms do contain the necessary information from which to compute the electron density profile. An example of a height-density profile obtained in this manner is shown in Figure 6. Ionospheric measurements of this type are used to identify the chemical, photochemical, electrodynamic, and meteorological processes of the upper atmosphere.

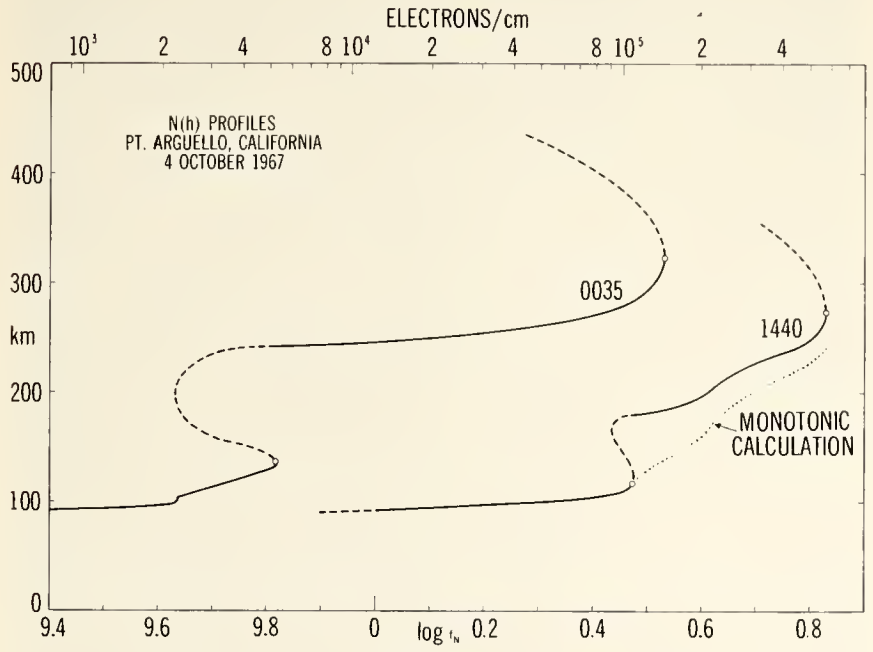


Figure 6. Height-density electron profile, recorded at Point Arguello, Calif.

Another technique, illustrated in Figure 7, provides information on smaller scale irregularities and air movement in the ionosphere. Here, the time variation of the amplitude of a fixed frequency radio echo is observed at four spaced receivers a few hundred meters apart. The fading patterns are similar, but displaced in time, suggesting movement of the echo amplitude pattern with respect to the ground. The Aeronomy Laboratory also compared "drifts" obtained by this technique with winds in the reflecting region observed in rocket- and gun-launched visible trail experiments.

New instrumentation was developed during the reporting period which combined these radio techniques with other similar techniques in a computer-controlled digital system with considerable flexibility. For example, this system can produce time-varying electron density profiles and ionospheric drift profiles (by performing the experiment of Figure 7 on a number of radio frequencies simultaneously) concurrently and in real time.

The Structure of the Upper Ionosphere and Exosphere. Above the altitude of maximum electron density, a radio signal that has not been reflected by a lower layer gen-

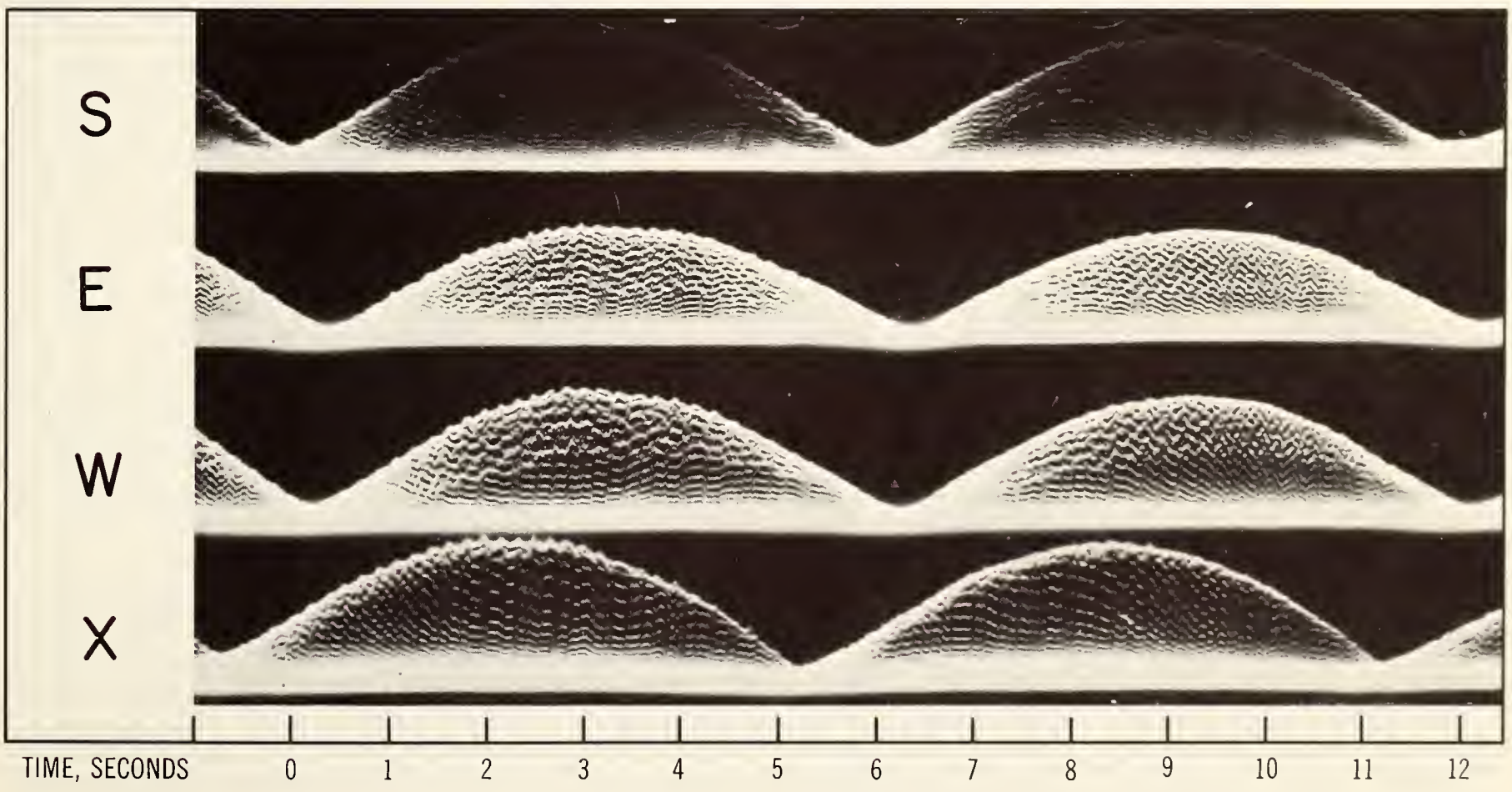


Figure 7. A four-channel spaced receiver drift recording made at Barbados, West Indies, February 18, 1966. The letters SEWX represent the southern, eastern, western, and center receivers, respectively.

erally escapes into outer space, and there is a critical frequency, which varies from time to time, above which escape takes place. Because some radio waves can escape the ionosphere into space, the study of the structure of the upper ionosphere is made difficult. Fortunately a very small percentage, even of the radio waves above the critical frequency, is reflected from the higher layers and can be observed on earth, providing a sufficiently large and sensitive antenna is used. The Aeronomy Laboratory's antenna at Jicamarca, near Lima, Peru, is one of the world's largest and gathers the data of the sort displayed in Figure 8, out to distances of 6,000 km.

Satellite Measurements

The availability of artificial satellites as platforms for making ionospheric measurements now permits direct data acquisition in the upper ionosphere. Studies with the "topside" sounder on Explorer XX, similar to the type of

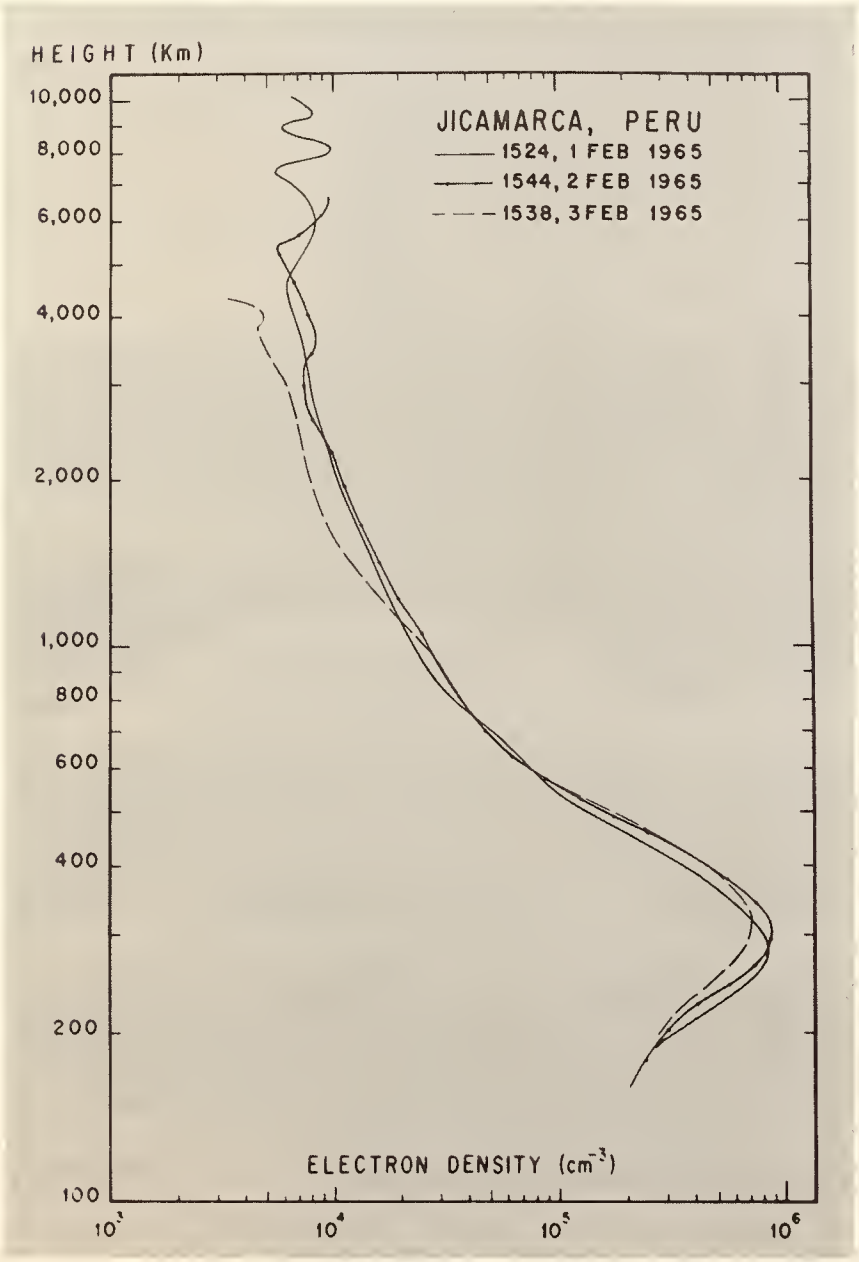
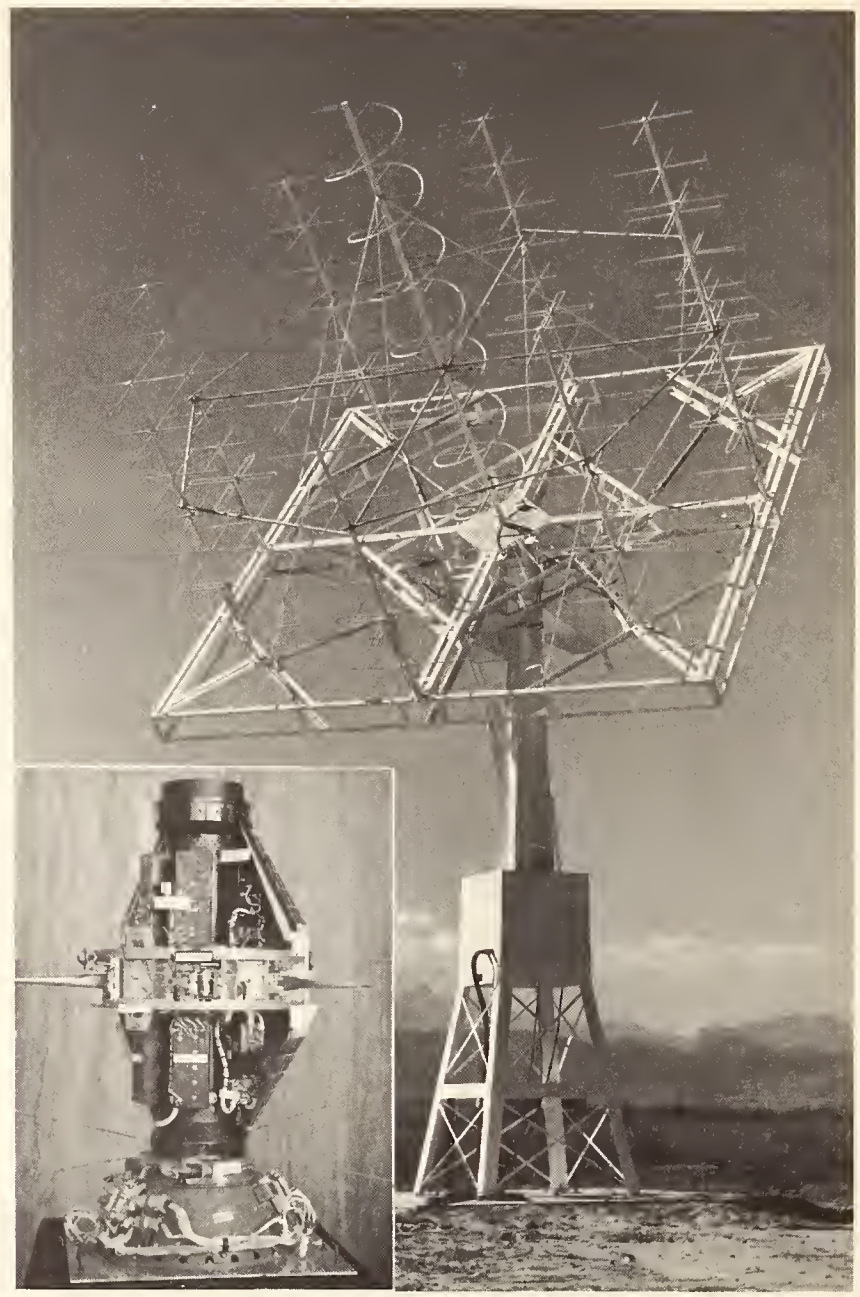


Figure 8. Height-density electron profile recorded at Jicamarca, Peru.



A satellite telemetry antenna on Gunbarrel Hill near Boulder, Colo. This antenna was used to control the Topside Sounder Satellite (insert), which examined the ionosphere from above.

radio studies made from the ground, have verified ground-based measurements, and in addition, have revealed the presence of duct-like irregularities along the magnetic field lines above the ionosphere, which serve to guide electromagnetic waves from one hemisphere to another.

Geomagnetic Studies

Earlier in this chapter, investigations of the earth's principal magnetic field were discussed and reference was made to the type of rapid fluctuations in the field produced by ionospheric phenomena. It is these short-term fluctuations which are the phase of geomagnetism of principal interest to aeronomy. Although the principal field arises within the earth itself, it does, at least in part, control the motions of upper atmospheric charged particles and guides the propagation of electromagnetic and magnetohydrodynamic energy. Fluctuations in the field are, in

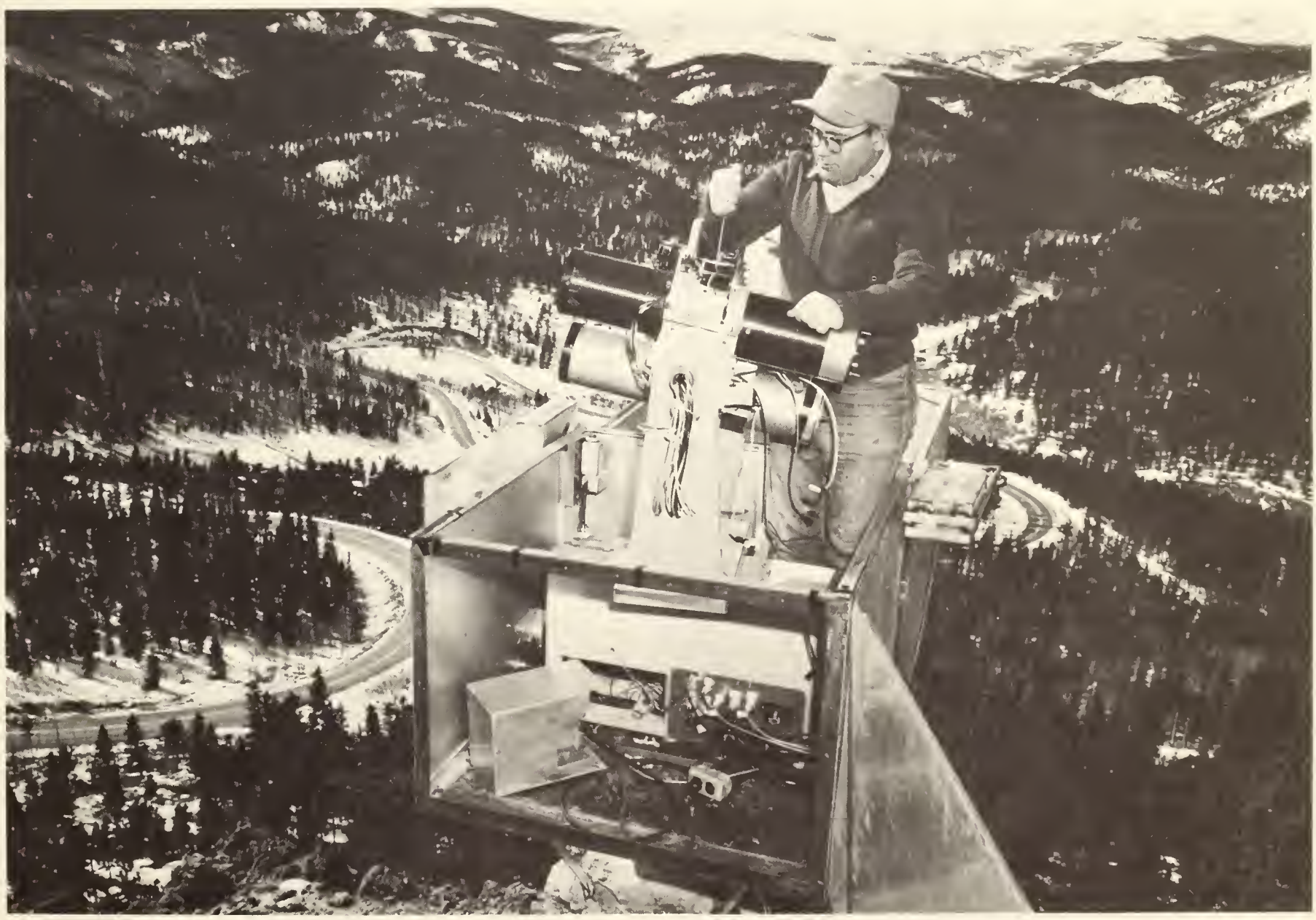
general, produced by changes in the solar environment. A knowledge of the resulting changes in the earth's magnetosphere and the currents generated within the earth's ionosphere is necessary for the proper interpretation of many aeronomical phenomena. ESSA scientists currently observe field variations at 11 stations throughout the world.

During the reporting period, investigations of both a theoretical and experimental nature included such topics as the spectral distribution of fluctuations in the earth's magnetic field with periods of 40 to 500 seconds, and the dispersion and polarization relations of hydromagnetic waves near one cycle per second. Using conjugately located stations during the June solstice period when the southern hemisphere site was in continued darkness, the absorption effect of the daytime ionosphere upon natural field-guided hydromagnetic signals was studied.

Aurora and Airglow

The dramatic phenomenon known as the aurora is a manifestation of the excitation to luminescence of atoms and molecules resident in the upper atmosphere by energetic charged particles moving under the influence of the earth's magnetic field, and therefore its study provides information concerning the composition and processes of the upper atmosphere and its interaction with the magnetic field. Auroral displays concentrate statistically in zones some 23° from the geomagnetic poles. Research results indicate that a complex of auroral phenomena exists which extends beyond this zone. For example, extensive arcs, invisible to the human eye because of their color, have been shown to extend toward the equator during times of geomagnetic disturbance. There is some evidence that these arcs occur in continuous bands following magnetic latitude parallels around the world.

Airglow also provides information on upper atmospheric composition and processes. This is a general glow, not easily seen from the earth's surface, but clearly visible to astronauts, and has been studied with photometers for a number of years. There are at least five airglow layers



At the ESSA Fritz Peak Observatory, a few miles from Boulder, Colo., a scientist adjusts a photometer used to study airglow and aurora in the night sky.

observed, the result of different physical processes producing different optical results—the most obvious being the one at a height of about 100 km.

An airglow layer less conspicuous to the naked eye, but a very interesting one scientifically, occurs in the so-called F region of the ionosphere centered at about 250 km. It is caused by photochemical reactions that are important not only in the production of airglow, but also in maintaining a steady-state balance of electrons in the ionosphere, and therefore its intensity gives an indication of the height of the layer over the earth.

Atmospheric Collision Processes

A few years ago, students of the upper atmosphere were seriously handicapped by a lack of quantitative information on the reaction rates of pertinent chemical reactions. Now, with the capability of simulating ionospheric conditions in the laboratory, new knowledge is being obtained to permit the analyst to develop accurate atmospheric models.

The chemical reactions which take place in the upper atmosphere are generally unfamiliar to students of classical chemistry. This is due to the fact that, under conditions of low density, significant ionization, and no restraining walls, rare atomic and molecular forms are possible. These forms are now produced in the laboratory and the rates of the positive ion-molecule reactions which control the ion composition and electron density in the quiet ionosphere above approximately 120 km. have now been measured directly.

Laboratory measurements of negative ion reactions of ionospheric importance have also been carried out. For example, it has been shown that a previously unsuspected ion, CO_3^-, may be more important in the lower ionosphere than any of the oxygen ions. Also, ion-molecule reactions have been found leading to the production of negative ions NO_2^- and NO_3^- which may be dominant atmospheric negative ions.

Laboratory studies of atomic and molecular collision processes controlling ionospheric composition and electron loss have also been made, and a negative ion chemistry scheme for the D region of the ionosphere has been formulated for the measurement of negative ion-neutral reactions.

Plasma Physics

The ionosphere has been simulated for the study of its physical as well as its chemical characteristics. Although some experimental work was performed during the reporting period, most studies were theoretical, pending the completion of a new plasma physics laboratory facility. Studies included a new treatment of electromagnetic wave scattering from a plasma and a new technique for interpreting scattering from ionospheric irregularities.

Considerable progress was made in the theory of transport coefficients (diffusion, electrical conductivity, etc.) and in their relationship to space and time correlation of fluctuations in the ionosphere. Experiments based on the theory verified the expected behavior of density fluctuations and pointed to a new method of experimental determination of diffusion coefficients without the necessity for a precise knowledge or control of boundary conditions.

Interaction With Lower Atmospheric Phenomena

The Meteorological Statistics Group of IAS has continued a statistical analysis of atmospheric oscillations and periodicities. Additional evidence has been found that solar and lunar thermal and gravitational tides are not only influencing the diurnal and semidiurnal variations of pressure, cloudiness, precipitation, etc., but may also be acting as an important forcing agent, producing the biennial oscillation that has been observed in the tropics and elsewhere. New statistical methods have been developed that are appropriate to the analysis and interpretation of these geophysical events.

5 ENVIRONMENTAL PREDICTION AND WARNING

The service products of prediction and warning programs are generally short-lived in nature and reach the user in the form of broadcasts, teletype messages, newspaper items, or similar types of presentation. As defined here, prediction and warning relate to more or less real-time events of a nonperiodic nature. Although description and understanding of environmental parameters are essential background factors, only programs specifically related to prediction and warning are discussed in this chapter.

EARTHQUAKE AND TSUNAMI PREDICTION

Strictly speaking, from the point of view of the spectrum of the environment, the prediction of earthquakes and tsunamis (seismic sea waves) should be treated separately, but will be discussed together because of the close relationship of the disciplines involved and the common use of data and equipment. These programs are related to Natural Disaster Warning System (NADWARN) and marine environmental activities, and are carried out by the Earthquake Mechanisms Laboratory of the Institute for Earth Sciences (IES), the Joint Tsunami Research Effort of the Institute for Oceanography (IO) and the University of Hawaii, and the Office of Seismology and Geomagnetism of the Coast and Geodetic Survey (C&GS).

Earthquake and Tsunami Research

At present, a service program in earthquake prediction does not exist. In fact, it may prove impossible to make useful predictions of these disasters in sufficient time to be of practical value, but the possibility of being able to do so is of sufficient national importance to direct ESSA's attention to research in this area. These studies are part of a broader investigation of earthquake mechanisms. They have broad application to the mitigation of the effects of earthquakes, through proper location of buildings and structural design as well as to prediction.

As pointed out earlier, ESSA operates a tsunami warning center at Honolulu, Hawaii, to provide warnings in the Pacific area. Research here is directed toward improved means of prediction, particularly with regard to runup.

Research and Development Facilities

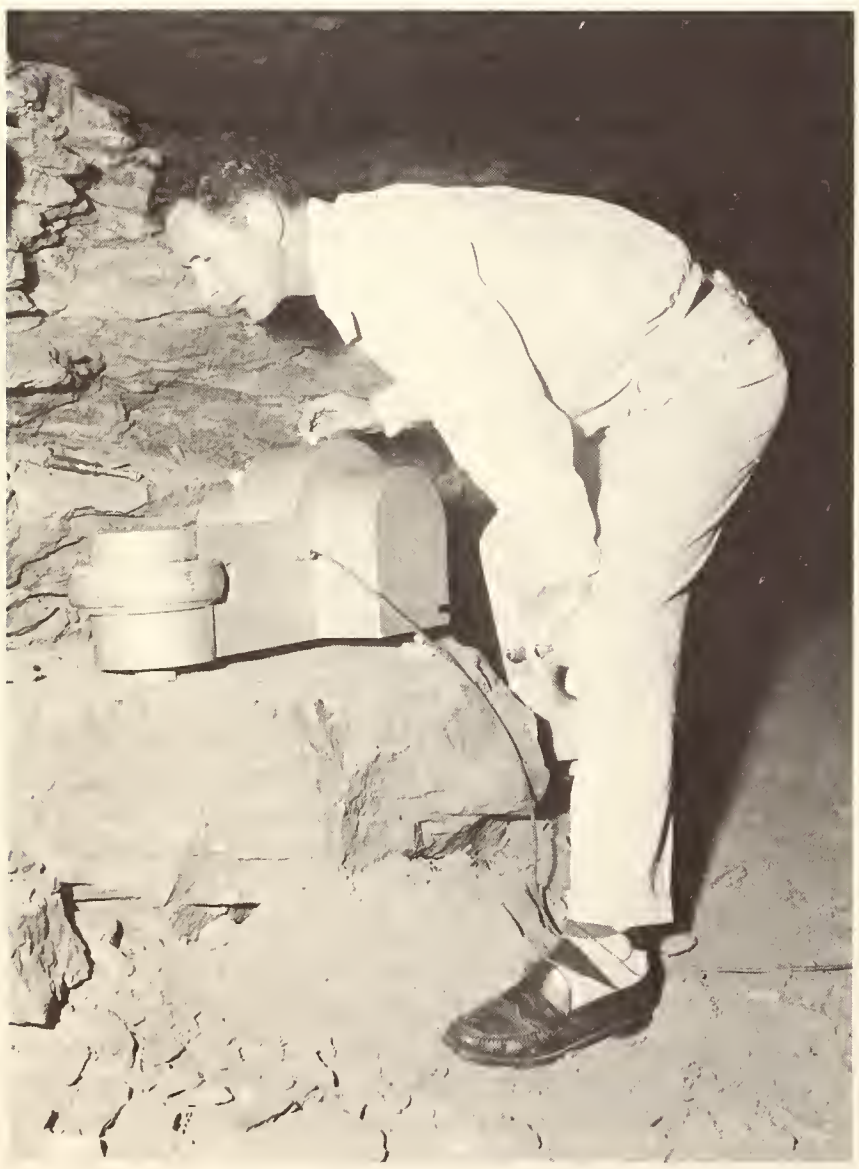
While data for this program are obtained for the most part from globally scattered seismograph stations, tide gages, and portable field instrumentation, there are a number of important fixed facilities. In the study of earthquake mechanisms, much of the emphasis has been on detailed study of small-scale earthquake processes in the vicinity of fault zones, and for this purpose the Earthquake Mechanisms Laboratory maintains special research facilities at the Castle Rock Magnetic Observatory, near San Jose, Calif., and its headquarters in San Francisco.

In addition, a major research facility has been developed by the Laboratory at the Stone Canyon Geophysical Field Station, 20 miles southeast of Hollister, Calif. The installations at Stone Canyon consist of a unique triangular array of high-frequency vertical component seismometers in bore holes at depths of 115 to 150 meters, with all three elements connected by cable to a central control building. Other equipment includes: Telluric current detecting elements consisting of two lead electrodes in each of the three boreholes; a triangular array of major strain meters, each 30 meters in length; a three-component surface seismograph adjacent to the top of the boreholes; a two-component Pellissier mercury-tube tiltmeter; a single element geomagnetic field variometer; and an automatic-recording weather station which provides hourly readings of rainfall, relative humidity, wind speed and direction, temperature, and barometric pressure. Data from these instruments are telemetered to the Earthquake Mechanisms Laboratory in San Francisco, where time and other information are added before recording on magnetic tape or hard copy.

A test of mercury tube tiltmeters to record tectonic tilt was conducted during the reporting period in a unique test facility at the Buena Vista Hills oil field north of Taft, Calif. This site is an ideal facility for tiltmeter tests since the surface over the field is known to be subsiding at a rate of several centimeters per year, and a close network of Coast and Geodetic Survey vertical and horizontal geodetic control points exists in the field. The tilting and subsidence presently taking place in the oil field is not tectonic in origin but is due to oil withdrawal. The rate of tilting, however, is well known from geodetic observations and quite closely simulates tectonic tilt. The area has been intensively studied geodetically and presents an excellent opportunity for the calibration and evaluation of various types of tiltmeters under controlled conditions.

Instrument and Systems Development

Portable Land Stations. Under ARPA sponsorship, the Earthquake Mechanisms Laboratory has developed Portable Land Stations to connect with its automatic data processing equipment in order to meet the special needs of the ARPA program. In addition to the features of portability, quick and easy installation, low power requirements, and versatility which characterize other portable systems, the Portable Land Stations have certain additional features needed for the mission of the Laboratory. For example, since extreme time accuracy is required, the time code generator has an accuracy of better than 10 milliseconds over a 10-day recording period. Provision is made in the control module at the time of data recording to compensate for transmission delay of the WWV or WWVH time signal so that all recordings are made on Greenwich Mean Time and no timing corrections need be made during data analysis. All data channels are automatically calibrated every 24 hours so that accuracy can be maintained over long periods of unattended operation. Finally, the Stations are hardened against adverse environmental factors and the rigors of transportation.



Adjustments being made to a Benioff Moving Coil Vertical Seismometer installed in Mammoth Cave, Ky.

DACAN System. The Portable Land Stations are a component of the Earthquake Mechanisms Laboratory DACAN system (Data Acquisition and Analysis) and work with it, either by means of magnetic tapes retrieved from remote locations or by direct telemetering from stations within range of the analysis center of the system at San Francisco. The DACAN system is capable of performing functions relating to seismic data including field recording on magnetic tape, tape search, and playback, dubbing, filtering, processing, and reduction to a final analog or digital hard-copy record. The system has several features which render it both versatile and economical. For example, it can accept any standard time input code and translate time into digital form for display and recording, display seismic signals for editing in both video and audio modes, search a selected time interval automatically, and print out hard copy on demand without stopping the tape.

Strong Motion Seismograph. A system embodying many of the same features is in the early stages of procurement by C&GS for use in the reduction of field data from regional studies. The Model II Strong Motion Seismograph was designed and developed by the Albuquerque Seismological Center of C&GS to record large accelerations and displacements arising from seismic events. It is a self-starting and self-programming instrument which is activated whenever an earth tremor exceeds the starting threshold. Excitation of the seismograph is accomplished by use of a pendulum starter sensitive to horizontal motion. Duration of the recording interval is adjusted and controlled by a time delay relay. Three components of displacement, three time traces, and three reference lines are recorded photographically, making the instrument self-contained. Provisions have been made for interconnection of two or more strong motion instruments where ganged starting and timing are desired.

LASA Noise Survey. In FY 67, the Earthquake Mechanisms Laboratory also initiated the investigation of noise levels at potential sites for Large Aperture Seismic

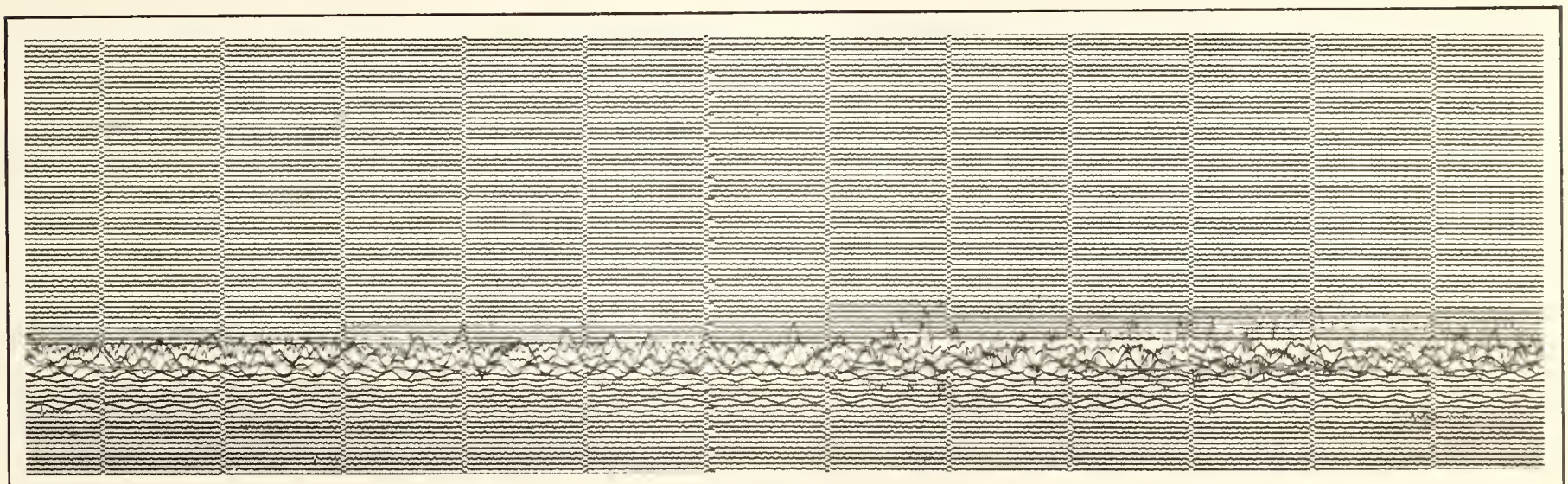
Arrays (LASA) which might be installed if the major nuclear powers were to reach agreement on a ban of underground nuclear detonations. The major portion of this program will be accomplished in FY 68 but the following preliminary work was achieved during FY 67: Response tests on portable seismographs; construction of two simple, lightweight reconnaissance seismographs, one of which was used in a preliminary background noise survey at a potential LASA site in the southwest Pacific; modification of four portable seismographs to permit continuous recording of wind velocity information on one track of magnetic tapes; the development of techniques for digitizing signals recorded on analog magnetic tape for the purpose of cataloging, labeling, storage, and retrieval of digital seismograms on library digital tapes. Methods have also been developed for applying standard and analytical techniques to these digital data for obtaining Fourier spectra, and cross correlation functions, etc.

Research in Earthquake Mechanisms

Seismicity. Several studies have recently been carried out to investigate the spatial and temporal aspects of seismic occurrence and energy release. During the reporting period, special equipment and personnel were sent by the Office of Seismology and Geomagnetism to investigate a swarm of earthquakes in the Rat Islands; Mexico; Puget Sound, Wash.; and Dulce, N. Mex. Location and analysis of approximately 1,000 shocks yielded important new knowledge about the seismic structure of these areas.

An investigation of the relation of seismicity in the Indian Ocean to other geophysical parameters was carried out. The data obtained permitted a fit to be made to a theoretical equation giving probable occurrence of earthquakes as a function of magnitude. Results of this study predicted a frequency of occurrence in the Indian Ocean area ranging from one every 50 years for magnitude 8 to one per year for magnitude 6 to 6¼.

Prince William Sound Earthquake. Perhaps the most comprehensive study ever made of an earthquake and its aftermath took place following the Prince William Sound earthquake in Alaska on March 27, 1964. For the past 3 years, C&GS has been engaged in preparing a complete report, the first two volumes of which have



Short-period seismograph record from Eskadalemuir, Scotland, approximately 6,725 km. from the Prince William Sound, Alaska, Earthquake epicenter. The first wave arrived at 03:46:24 GCT, March 28, 1964. (Below) The general area of Alaska affected by the Prince William Sound Earthquake.

been published. The physical changes which resulted in the earth's crust at the time of this earthquake are greater than those reported for any previous earthquake. The geodetic and hydrographic surveys made after the earthquake show vertical and horizontal changes of more than 15 meters in each direction over a region of several hundred square km. near the south end of Montague Island. This large section of the earth's crust was lifted and moved southward. Tectonically, this movement has a strong correlation with an unusually large positive gravity anomaly centered over Prince William Sound.

The entire area of the Sound was affected. Changes in elevation varied from plus 15 meters to minus 2 to 3 meters along a broad arc extending along Cook Inlet sweeping north toward Anchorage and the northern side of the Chugach Mountains. The area of horizontal movement also extended to this outer limit. There is a strong tectonic correlation with a pronounced gravity low in this region of subsidence. The geographical extent of this disturbance was so great that it has not yet been possible to allocate sufficient effort to resurvey in detail all the areas which have shifted in position and elevation. Long-range plans provide for additional resurveys and extensive research in this region, in order to obtain more complete information relating to the Prince William Sound earthquake, and also to provide basic information which can be used for the development of the earthquake prediction program.

Fault Creep Studies. Monitoring continued at the Almaden Winery near Hollister, and evidence of movements, probably fault creep, which have occurred along the Hayward Fault between San Pablo Bay and Hollister was investigated.

In the Hollister area, the Earthquake Mechanisms Laboratory, in collaboration with the California Division of Mines and Geology, has made extensive surveys of fault creep in and near the city of Hollister by observing displaced curbs, pipelines, and buildings; similar features on the San Andreas fault near San Juan Batista have been mapped; and reconnaissance surveys for such features along faults in other California locations have been made. Progress is reported in the development of fault creep recorders designed for continuous monitoring of slow earth motions across zones broader than those which can be accommodated by present creep meters.

Negotiations are now underway for the selection of a specific site for a geophysical field station in Marin County, Calif. This area is somewhat different from other sites along the active faults in California since it is a relatively quiet seismic area and is typical of areas suspected as possible sites for the strongest earthquakes.

Microearthquakes. A theoretical study of microearthquakes was initiated during FY 66 by the Earthquake Mechanisms Laboratory. It has been stated once or twice in the literature by Japanese workers that perhaps some significant interpretation of the frequency and magnitude of very small earthquakes can be made just before and after a larger event. The shape of the frequency-magnitude curve for foreshocks of an earthquake was noted to be significantly different from a frequency-magnitude curve made after the event. Also, the shape of the curve immediately after an event was, in general, the same as that of ambient background during the long period between major seismic events. In pursuing this possible clue to earthquake prediction, the Laboratory was able to obtain microearthquake information from three dissimilar geologic areas in the same general region during the same time period. Data from Castle Rock (on a portion of the San Andreas fault where slippage is not current); from Mt. Madona (on the Hayward fault where there is evidence of current fault slippage); and from the Harris ranch (approximately at the intersection of the San Andreas and Hayward faults where the rock formations are considerably fractured) were obtained for a period of several weeks during March 1966. Efforts are now underway to reduce these data and determine the location of the small earthquakes in each of the three regions. Upon completion of this phase, a study of the frequency versus magnitude characteristics of microearthquakes will be made for each year.

In the area of microearthquakes, studies are divided into two categories: (1) studies of ambient levels of microearthquakes and secular changes in these levels, normally carried out through continuous recording by permanent and semipermanent stations; and (2) studies of aftershock of larger earthquakes, conducted by means of mobile seismic equipment to saturate the epicentral region for some limited period of time following the main shock.

Other microearthquake studies in the aftershock category during the reporting period included an investigation of earthquake effects and aftershocks of a strong earthquake near Truckee, Calif., conducted by a reconnaissance team from the Earthquake Mechanisms Laboratory, and the installation of five portable three-component land stations in a cluster surrounding the epicenters of two large earthquakes which occurred northwest of Parkfield, Calif., on June 28, 1966. Critical data recorded by these stations have been used in cooperative studies by C&GS and the University of California.

At present, five microearthquake detection stations are in continuous operation along the San Andreas fault, spaced at intervals of approximately 40 km. from Point Reyes in the north to Stone Canyon in the south. An additional station is in continuous operation east of the Hayward and Calaveras faults. This detecting array consists of Bear Valley Observatory, San Andreas Lake Observatory, Russel Varian–Castle Rock Magnetic Observatory, Holy Cross Observatory, Stone Canyon Observatory, and Mt. Diablo Observatory.

Tsunami Research

Since the establishment of the Seismic Sea Wave Warning System (now the tsunami warning system) by C&GS in 1948, considerable effort has been applied

to improving tsunami prediction techniques. Not all submarine earthquakes produce tsunamis, and when these great waves are produced, the subsequent behavior is critically influenced by underwater topography. Hence prediction is by no means simple, even though earthquakes can be rapidly identified and located. ESSA's Institute for Oceanography (IO) has established the Joint Tsunami Research Effort (JTRE) in Honolulu, in cooperation with the University of Hawaii, to study underwater seismic phenomena and to develop improved methods of tsunami prediction. During the reporting period, a scientist of IO, working at JTRE, prepared a computer program to describe certain aspects of tsunami propagation. The program can be applied to a tsunami originating at any position in the Pacific Ocean and describes the convergence or divergence of energy at any other point in the Pacific. This research has furnished one of the factors essential to the prediction of tsunami runup on the coasts around the Pacific.

PREDICTING THE OCEAN AND ATMOSPHERE

For many decades, man has attempted to forecast the weather based upon the disciplines of meteorology. Similarly, the periodic tides and currents of the oceans have been described and predicted with varying degrees of accuracy for many centuries. Only recently, however, has science approached the study and prediction of the interaction of the two environmental media as a single system problem. ESSA's programs in meteorology and marine environmental prediction reflect this interdisciplinary approach.

Weather and the State of the Sea

The interaction between the waters of the earth and the atmosphere provides the moisture and much of the energy that creates weather. Study of the interaction between these two fluid media surrounding the solid earth is essential for understanding, predicting, and controlling the complex processes of weather. Thus, ESSA has a major interest both in forecasting the behavior of the marine environment and determining the effect of marine environmental processes upon weather. ESSA's activities in this field include the development of improved equipment and techniques for data acquisition, analysis, prediction and dissemination; design of forecast and dissemination systems; research in the fields of synoptic and mesoscale meteorology; and satellite meteorology.

Organization and Facilities for Research and Development

Research, development, and test of instrumentation and forecasting methods and systems, is performed by four elements of the Weather Bureau: the Equipment Development Laboratory (EDL), the Techniques Development Laboratory (TDL), and the Test and Evaluation Laboratory (TEL) of the Systems Development Office (SDO) at Silver Spring, Md., and the Development Division and Extended Forecast Division of the National Meteorological Center (NMC) at Suitland, Md.

Research in the mesoscale meteorology of hurricanes, tornadoes, and severe local storms is carried out by the National Hurricane Research Laboratory (NHRL) at Miami, Fla., and the National Severe Storms Laboratory (NSSL) at Norman, Okla., of the Institute for Atmospheric Sciences. These Laboratories make extensive use of the instrumented aircraft of the Institute's Research Flight Facility (RFF) at Miami, Fla.

Research and development in satellite meteorology and instrumentation is carried out at the National Environmental Satellite Center (NESC) at Suitland, Md.

Instrument and Systems Development

ESSA's program in instrument and systems development covers meteorological instruments and facilities, satellite sensors for atmospheric and marine environment studies, and data handling and display systems.

Meteorological Instruments. EDL is responsible for translating basic knowledge in meteorological equipment technology into practical instrumentation.

A number of different types of humidity gages (hygrometers) were examined during the reporting period for varying applications. Included were a lithium bromide dew cell for application to automatic meteorological observation stations, infrared absorption hygrometers for airborne instrumentation for RFF, and improved hygrometers for radiosonde applications. Digitized pressure instrumentation was also developed for application to remote systems.

The primary instrument used by the Weather Bureau for measuring cloud height is the *rotating beam ceilometer* (RBC). During the reporting period, a program aimed at providing major improvements to this instrument, e.g., improving the signal-to-noise ratio of the system and digitizing output data, was continued with substantial gains toward project objectives. Automatic phasing has been incorporated and automatic gain control is being developed to make future units adjustment-free for the operator.

Test and evaluation of a prototype model commenced in August 1966 is scheduled for completion in June 1968. Results obtained from data covering a period during which low cloudiness occurred indicated a number of problems in using the rotating beam ceilometer as an input to an automatic data processor. An investigation is being conducted to establish the best method for presenting cloud information to the user.

Work continued during the reporting period on digitizing the output of the rotating beam ceilometer. Basically, the photographs of RBC displays were analyzed and evaluated as basis for digitally establishing cloud height. Results of this analysis are being translated into electronic circuitry.

One of the most important tools of the meteorologist is the weather balloon, whether it is used with a theodolite, radar tracked, or used to carry a radiosonde aloft to transmit meteorological data back to ground stations.

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Launching a weather balloon-radiosonde combination.

One of the problems in the use of balloons is the limiting angle with respect to the horizon, below which signals can no longer be received from the balloon under observation. This problem, particularly severe during periods of high winds, has been partially solved in the past by the rather costly method of using radar transponders. A contract was therefore granted to study and recommend a balloon with optimum rate of ascent with a view toward the solution of the limiting angle problem. The effects of various balloon properties as they relate to ascent rate were investigated through the use of a computer model. The final report indicated that the Weather Bureau can realize a substantial saving by using low-cost fast-rise balloons in place of transponders. The study further recommended the establishment of a research and development program to design a balloon with the aid of a computer to meet these requirements.

Because of the high cost and relative scarcity of helium, considerable interest has been focused on finding economical means to generate hydrogen for inflating weather balloons, while eliminating the hazards associated with its use. A hydrogen balloon inflation system consisting of an electrolytic generator, a specially designed structure for housing the generator, an automatic hydrogen cutoff valve assembly, a contoured balloon table, and a hydrogen sensing alarm system are planned for installation at SDO's Test and Evaluation Laboratory at Sterling, Va.

A hydrogen generator has been purchased, delivered, and installed at the Laboratory, and is operating satisfactorily. Functional tests are being conducted to determine if modifications are required, particularly, to ascertain the comparative cost of *in situ* generated hydrogen with that available through commercial sources, and to evaluate the other elements of the system with respect to their suitability for field application. Positive test results would lead to significant dollar savings through the reduction of gas costs.

The safety aspects of using hydrogen in the field were investigated through a contract study. A report with recommendations for safe operation of a hydrogen system was submitted during FY 67 with evaluation of the recommendations scheduled for early FY 68.

There are many remote locations where it is difficult and expensive to maintain weather observers, but from which data are essential. Hence, there is a critical need for satisfactory unmanned meteorological observation stations to meet this requirement, as well as a need for supplementary observations at locations such as busy airports during periods of marginal weather.

A sample operational observational program for the Automatic Meteorological Observing Station (AMOS V) was initiated using a laboratory prototype, at Washington National Airport. The aim of this system is to acquire, process, and display observational data and provide automatically an indication of significant changes in the weather. On the basis of the experience gained, a complete system test will be conducted by the Test and Evaluation Laboratory, designed to determine the manner in which AMOS V can best aid and supplement the observer at high-density airport terminals.

The testing and evaluation of current and new observational methods and related instrumentation to meet the needs of the National Meteorological Service has been conducted by a Weather Bureau group at the Federal Aviation Administration's National Aviation Facilities Experimental Center (NAFEC), at Atlantic City. Here, by interagency agreement, the Bureau established a branch to operate an experimental weather "test bed" environment. Components of the test bed included a mesometeorological network (mesonet), an upper air facility, a visual range facility, and an AMOS IV (automatic observatory) facility.

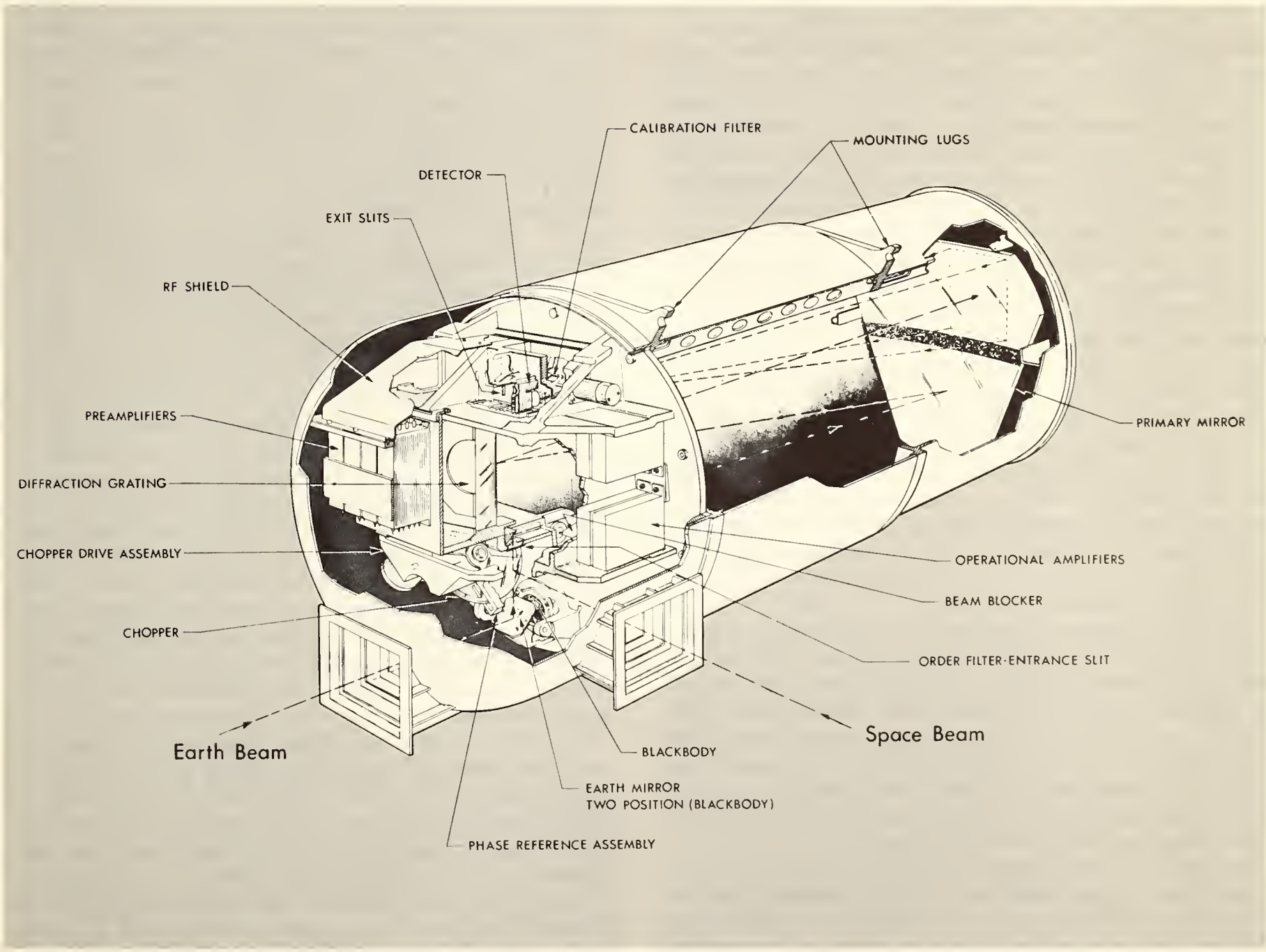
The primary objective of NAFEC was to develop new methods and improved procedures for observing and measuring local meteorological phenomena. This included

studies with the Systems Research and Development Service of the FAA and interagency projects for aviation weather research and development. Selected stations also reported three levels of soil temperature. Data collections were punched on paper tape and later transferred to magnetic tape for computer processing.

Satellite Sensors. ESSA's National Environmental Satellite Center is actively involved in the development of new and improved satellite sensors for meteorology and oceanography.

A major portion of the effort during the reporting period has been related to the development of sensors to detect and analyze radiation from the atmosphere and surface as a means of increasing the amount of significant environmental data which can be obtained from satellite-borne instruments.

The Satellite Infrared Spectrometer (SIRS), which is to be included in NASA's Nimbus B spacecraft, has proceeded through the final calibration stages of the prototype instrument under NASA sponsorship. This model is presently in an advanced integration stage with the spacecraft. The instrument is designed to measure the radiation flux from the atmosphere and the earth's surface in several discrete wave-length intervals in and near the 15-micron carbon dioxide band, and at one interval centered at 11.1 microns in the water vapor "window." Measurements in the carbon dioxide band will be used to calculate the vertical temperature structure in the upper troposphere and in the stratosphere. Measurements in the water vapor window will be used to obtain the temperature of the earth's surface and of the tops of clouds.



The Satellite Infrared Spectrometer (SIRS), which is designed to measure the vertical temperature profile of the earth's atmosphere from satellite altitude.

An ESSA-developed hand-held spectrographic camera was used by Gemini 5 astronauts to obtain spectra of sunlight reflected from clouds in the vicinity of an important oxygen absorption band. The transmittance measurements at selected wavelengths inside the band offered a means of measuring the amount of oxygen in the optical path, and therefore permitted an estimate of the cloud top altitude. The Gemini results indicated that the method was feasible, and a subsequent design study has led to the development of a new automatic instrument for use from an aircraft and eventually from an unmanned satellite.

An infrared interferometer is in an advanced stage of development for taking spectra of the atmosphere to improve the signal-to-noise ratio and provide a greater working aperture. A laboratory model has been tested and is being miniaturized for preliminary balloon experiments.

Data Handling and Display Systems. Instruments and sensors are acquiring meteorological data in ever-increasing amounts which must be transmitted, digested, and analyzed to prepare forecasts and warnings, and disseminated to the user in a form suitable for his needs. The System Plans and Design Division of the Weather Bureau's System Development Office is conducting a number of system design studies which will ultimately culminate in the design of the National Meteorological Service System to perform these functions in the most economical and efficient manner. These studies cover the requirements and associated benefits for the various service programs and the systems and sub-systems needed to meet the requirements in an optimum manner. Based upon an analysis of user requirements, studies were made of the feasibility of automating surface weather observation stations as a function of the level of data flow required. Completion of this study awaits a comparison of various alternatives.

The National Environmental Satellite Center (NESC) has improved the rapid utilization of satellite cloud photography by employing digital techniques. Digitized video data with virtually worldwide coverage, calibrated and mapped in the form of brightness values, are currently made available to users.

A radio telemetry system for remoting weather sensors beyond reasonable cable lengths is under development at the Equipment Development Laboratory. This system is planned around a low-power VHF radio link and will have a range of 5 miles or greater, where line-of-sight transmission is possible. The remote electronics are fully solid state, and are designed for battery operation. An engineering model of this system for use at airports was completed and successfully tested.

A method of improving the display of precipitation data from weather radar by producing intensity contour lines, previouly developed by NSSL, is now undergoing further development by EDL for operational use with the existing WSR–57 Weather Bureau radars.

The development of the Video Integrator Processor (VIP) was completed during the reporting period. This unit provides six levels (totaling 60 db) of precipitation intensity contour on a standard Plan Position Indicator (PPI) display. These contour levels are presented simultaneously with each sweep of the radar antenna or in any combination at the operator's discretion. The equipment was tested at Washington National Airport during the reporting period.

Test and evaluation of the Video Integrator and Processor (VIP) commenced at Washington National Airport in February 1967 and continued through mid-June. At that time, the unit was removed from the radar for further bench testing at the Sterling Research and Development Center. A final report was scheduled to be released in FY 68. Preliminary findings indicate that the basic design of the unit is sound and that it is extremely useful for the radar meteorologist. In addition to providing a more useful visual display for the weather observer, the device also permits digitization of precipitation data in such a form that it can readily be transmitted for hydrologic purposes over conventional telephone lines, or fed directly into a computer for analysis.

A weather radar remoting system (WB–RATTS/65) developed under contract with the Equipment Development Laboratory was tested by the Test and Evaluation Laboratory in the Houston/Galveston area and Washington, D.C. Testing in the Kansas City area commenced during FY 66. The purpose of this system is to provide real-time weather radar data to stations not collocated with a radar but having a geographic area of responsibility within the effective range of one. It is anticipated that the availability of radar data at nonradar stations will significantly increase the basic effectiveness of the station in performing its assigned public service functions.

In this system, the radar video bandwidth is compressed to less than 3 kHz by scan conversion techniques, making it suitable for transmission over standard quality telephone lines. At the remote station, the display is reconstructed on a storage tube which, in turn, is viewed by a standard closed circuit TV camera. The system output to the operating meteorologist is a standard 21-inch TV display of live radar data. A single transmitter at a radar site can provide data up to eight remote stations, each of which can have up to five TV displays. The system also provides the radar meteorologist with the capability of adding interpretive annotations directly onto the transmitter display and communicating with all remote stations via direct voice telephone line.

An interim report covering the Houston/Galveston tests was released in November 1966. This report concluded that with the exception of the closed circuit TV camera unit, the system was basically sound from an engineering standpoint. It was also concluded that the system product was of significant value at remote Weather Bureau, FAA Flight Service, and Air Force and Navy Weather Service stations. A new closed circuit TV camera is currently under test in the Sterling Research and Development Center receiver and, to all indications, it is totally acceptable. A final report was scheduled for release in the fall of 1967.

In Texas, the Galveston radar has been remoted to the Weather Bureau Airport Station at Houston, and to Ellington Air Force Base. Tests being performed in that area are predominantly operational in nature with the establishment of standard operating procedures being the prime goal. Remote displays of the St. Louis, Wichita, and Des Moines radars are being provided to meteorologists at the National Severe Storm Forecast Center (NSSFC) at Kansas City to augment the information provided by the local radar. The availability of live radar data covering most of the Midwestern United States should enable NSSFC personnel to perform their assigned duties in a more effective manner. Various techniques for combining data from the four sources into a single large area composite will also be tested. A final test and evaluation report is scheduled for release in the near future.

During the reporting period, a closed circuit TV studio was designed, developed, and installed at the National Hurricane Center by EDL personnel and is now undergoing tests by TEL. This system is designed to expedite dissemination of information to the public on hurricanes and other severe weather conditions, with minimum interference to Weather Bureau personnel during a period of critical activity. The televised information, consisting of briefings by meteorologists, direct views of the weather radar, and other information, is made available, live, to the local TV stations and networks for dissemination to the public.

The IBM 7040/1401 Data Processing System at NHRL takes digital data recorded aboard RFF aircraft, corrects it for errors, correlates it with time and positions, and prints out all variables. Work continued during the reporting period to improve all phases of the system. Much hand editing was eliminated and programs were combined to reduce the time and cost of analysis.

The technical feasibility of exploiting different features of electrical signals produced by lightning in order to locate and follow areas of lightning and assess its severity was established by NSSL. This successful demonstration led to a contract for the development of an operational system to provide airline meteorologists and operators with real-time displays and information about lightning over a range of 100 miles from operation centers. This system will provide a basis for safer utilization of airspace during thunderstorms.

Forecast Research and Development

Research and development relating to the improvement of operational weather forecasting is the responsibility of the Weather Bureau. The Bureau's Techniques Development Laboratory concerns itself primarily with the aspects of forecasting that are of daily interest to the forecaster, while the research program of NMC is concerned with the development and improvement of numerical prediction techniques on a global scale, and for an extended period of time.

Forecast Techniques Development. TDL translates advances in basic meteorological knowledge into improved operating procedures. To achieve this goal, TDL conducts and sponsors applied research and development directed toward the improvement of analysis and forecast methods for producing weather information primarily intended to be issued directly to the public and other user groups.

During the reporting period, the use of probability statements in weather forecasting became much more widespread. These statements provide the forecast user with quantitative information concerning the degree of uncertainty in weather events and enhance the economic value of the forecast. This type of forecast is based to a great extent upon a statistical analysis of experience. Quality control of these forecast probabilities is essential to their continuing value in decisionmaking, and a 2-year study of this subject has been conducted for the Weather Bureau. A set of guidelines has been devised whereby the forecaster can check continuously to insure that his forecasts are adhering to standards.

An objective numerical method of prediction of short-term meteorological events called REEP (Regression Estimation of Event Probabilities) was applied during the reporting period to forecasting the probability of precipitation occurrence during 12-hour periods. The results obtained using this method, which involved no subjective judgment, were compared with other forecast methods for accuracy. A final report on the evaluation of REEP as an aid in forecasting ceiling and visibility parameters was issued in August 1966.

During FY 67, several experiments demonstrated that improved forecasts could be obtained by incorporating the effects of precipitation and moisture into the system. Additional work along these lines will be carried out during FY 68.

Climatological probabilities of precipitation using data from 108 stations in the conterminous United States have been computed for 6-, 12-, and 24-hour periods for each month of the year. In addition, probabilities are being computed relative to wind speed and direction and time of day for nine stations in the Northeastern States in 6-hour and 12-hour periods.

An investigation of the synoptic climatology of precipitation at a network of 280 stations in the Plateau States of the western intermountain region is being carried out for the Bureau of Reclamation. The first phase of this project has indicated that a surprisingly close relationship exists between the positions and intensities of cyclonic systems at the 700 mb. level and the probability and amounts of winter precipitation in this region.

During FY 67, the second phase of the synoptic climatological study of the West extending the investigation to three additional atmospheric levels was completed. Substantially better results have been noted for the lowest levels. Another investigation of precipitation phenomena is a special study being carried out for the Tennessee Valley Authority relating circulation features to winter precipitation at nine drainage basins in the Tennessee Valley.

Numerical prediction models have been programed for a grid covering the Eastern United States with a 50-mile spacing. Emphasis has been placed on predictions of sea-level pressure and precipitation for projection up to 16 hours. Input data are the latest available so that the prognostic information could be sent to field stations in time to influence early morning forecasts.

The TDL fine-scale numerical models described above have been tested over a 3-month period and found to produce better forecasts of precipitation and sea-level pressure for the first 12 hours of the forecast period than large-scale NMC models. The possibility of implementing the TDL models on an operational basis during the next fiscal year is now being investigated. Techniques are also being developed for local station use, which will use centrally produced guidance as well as local data.

Nationwide forecasts of maximum and minimum surface temperatures are being produced automatically twice daily at NMC by a program developed in TDL. This program applies multiple regression techniques to relate historical files of surface temperatures to concurrent pressure distribution aloft, and is used to forecast the maximum and minimum for each of 119 stations in the United States and Southern Canada. To maintain accuracy, a new set of equations is developed for each 2-month period. In its operations, the program uses as inputs numerical analysis and forecast of pressure distribution aloft, as well as synoptic reports of actual maximum and minimum temperatures. The equations are applied repeatedly, first to observations and then to forecasts, so as to produce a series of predictions up to 2½ days in advance; these are then printed out automatically in map form.

During FY 67, the system was extended to an additional 25 stations, so that automated temperature forecasts are now prepared for 143 cities, including 12 in Canada. The system has been revised so that missing temperature reports are filled in automatically from previous forecasts with the barotropic mesh model used as input. These revisions have made forecasts available about 4 hours earlier than was previously possible.

Aviation Weather Forecasting. A commercial TV tower in Philadelphia, Pa., has been instrumented with meteorological sensors at five levels by the Drexel Institute of Technology, under contract with the Weather Bureau. The tower supplies data which are used in developing techniques for prediction of mesoscale weather phenomena in the Philadelphia area. The effect of the tower on wind measurements was investigated, and a climatology of wind, temperature and moisture profiles is being compiled. Remote readout equipment was installed at the Philadelphia Weather Bureau Airport Station for the purpose of evaluating the usefulness of this type of data in real-time operations.

Mesoscale weather phenomena were studied using several avenues of approach. Pennsylvania State University completed a contract on condensation nuclei and fog formation with the use of a 70-foot fog tube. The air within the tube was saturated with water vapor and resultant variation of light transmission measured. Measurements of electrical potential were made simultaneously to determine the role of ambient electric field on the fog formation process.

The Washington mesonetwork was used for documenting mesoscale fog and precipitation studies during the reporting period. Recording raingages were installed at each project-operated station. The mesoscale data were used to relate fog to tower wind speeds, turbulence in the wind-flow, temperature inversion structure, and horizontal divergence in the wind field.

Several studies have been conducted as part of a long-range program for improving the prediction of airport weather phenomena for short periods. Previous work by a contractor on the general problem of statistical prediction of rare events was completed in FY 67. A method of consolidating predictor information in a number of joint variables was developed and tested for predicting low ceilings at Seattle 3 hours in advance.

Emphasis was placed on improving the forecasts of change from high to low ceiling. The general approach was to develop "inhibitor variables," to identify initial conditions which would never be followed by a low ceiling, and then to develop specialized predictors on the remaining sample, which would consolidate the small predictive contributions of many variables. The technique surpassed any previous objective forecasting technique in producing successful forecasts of change of ceiling over a wide range of ceiling heights.

The REEP method of analysis mentioned previously for predicting airport ceiling and visibility was tested operationally over a period of 7 months, with predictions being sent to six Aviation Forecast Centers on a regular basis. During the same time period, forecasters were asked to prepare special subjective forecasts for comparison with the numerical predictions. Evaluation of the forecasts has indicated that the REEP probability forecasts were of value as guidance in the preparation of subjective forecasts, particularly for long-range projections.

A program to develop automated techniques for predicting ceiling and visibility at aviation terminals was planned. A series of tests of increasing complexity was initiated to prove or verify these predictions. Experiments are being carried out at 12 terminals for forecast periods up to 12 hours. Statistical methods are combined with products of synoptic- and subsynoptic-scale numerical prediction. Preliminary prediction model equations which had been tested previously out to 7 hours have been extended to 12-hour prediction.

Studies of clear air-turbulence (CAT) continued during the reporting period. It appears to be more useful to concentrate on areas with unusually high probability of moderate or greater turbulence than to attempt to use all the occurrences, many of which are quite isolated. Two forecast criteria have been suggested. Significant turbulence should be forecast (1) in areas within 150

miles of a jet stream whose maximum wind speed is at least 100 knots or (2) in areas within 150 miles of a well-developed trough line with a sharp directional wind shear across the trough line. The use of these criteria with data used in the study indicates that 60 percent of all the occurrences would be included in a forecast area comprising 34 percent of the total area.

New turbulence data have been collected for use in a study of the relationship between large variations in ascensional rates of rawinsonde balloons and CAT occurrences. Two 10-day collection periods, in December 1966 and February 1967, were limited to flights within a 100-mile radius of selected rawinsonde stations and within +2 hours of observation time. These CAT occurrences are also being analyzed in relation to their associated meteorological data.

During FY 67, analysis of two special 5-day turbulence collection periods in December 1964 and March 1965 was completed for FAA. Special attention was given to areas with at least 25-percent frequency of moderate or greater turbulence. Vertical wind shear appears to be an important parameter along with 12-hour changes in wind speed.

Fire Weather Forecasting. Research by Weather Bureau personnel on fire weather continued during the reporting period at Riverside, Calif., funded by the U.S. Forest Service, on the following topics:

1. Structure of the Santa Ana winds.
2. Penetration and modification of marine air.
3. Characteristics of flow across coastal ranges.
4. Valley wind convergence zones.
5. Mesoscale weather patterns in mountainous terrain.

Additional research is planned to define and describe regional and mesoscale weather patterns in the Pacific coastal region which affect the ignition and spread of wildfire.

A study was begun by TDL to develop forecast techniques for prediction of afternoon wind speed and direction during the summer months for a mountain location in south-central Idaho. This study will be based on both surface and upper air data. It is planned to extend this work to other locations and other weather elements.

During FY 67, studies were initiated by TDL to develop techniques for prediction of maximum temperature, minimum relative humidity, and wind at 89 selected stations throughout the United States. The basic weather data were available on magnetic tape for a 10-year period from an earlier study involving these stations. In addition, data at some 30 local stations in the Los Angeles Fire-Weather District were used to determine cross-correlations between the stations and central key stations. Analysis of some 200 Santa Ana situations in the Los Angeles area was also begun.

Agricultural Weather Forecasting. Several studies were underway during the reporting period to investigate weather phenomena of particular importance to agriculture, such as the occurrence of freezing temperatures during the growing season and precipitation probability during the drying season for crops. Recent studies include: winter precipitation probabilities in Virginia and South Carolina, freezing conditions during the growing season in north-central California, the effect of wind on spring freezing of crops in the State of Washington, and studies of tobacco drying conditions in South Carolina and Kentucky.

Marine Environmental Forecasting. Special emphasis has recently been placed on improving prediction of the marine environment, and providing broader forecast and warning services to marine interests. During the reporting period, a plan was developed for a National Marine Weather Service by SDO. The plan calls for establishing six Marine Forecast Centers to furnish support to operations on the high seas, in Continental Shelf areas, and in coastal and inland waterways. Under the plan, the acquisition of marine observations and the number of dissemination facilities will be expanded. In addition, it is planned to develop improved marine forecast capability and more user-oriented service products.

Research in Numerical Prediction

The equations which describe the motions of the atmosphere and its thermodynamic state have been well known for many years. However, due to their great generality and a lack of detailed data on a global basis, it has not been possible to solve them except under greatly oversimplified conditions. The high-speed computer, and the increasing availability of meteorological data in nearly real-time from many parts of the world, have made possible the solution of these equations—at first in a relatively simple form, but later in an increasingly complex and more complete form. This capability permits the numerical prediction of the state of the atmosphere, at least for short periods of time, with ever-increasing confidence.

Primitive Equations. The complete basic equations of motion and state, taken together, are known as the *primitive equations,* and have been difficult to use, until recently, because of certain mathematical difficulties. Because the vertically averaged flow is fairly well represented by the flow at mid-atmosphere (500 mb., or about 18,000 feet above sea level), early models were two-dimensional representations using real atmospheric data from that level as initial data for forecast. Since these models did not take account of energy sinks and sources, they were known as *barotropic* models (i.e., models constructed so that surfaces of constant density or temperature are coincident with surfaces of constant pressure). Later models were three-dimensional in nature, and provided for transformations between kinetic, potential, and internal energy. These so-called *baroclinic* models were "filtered" in the sense that certain factors leading to mathematical instabilities were suppressed.

More recently, following solution of some of the mathematical problems involved, it has been possible to work with the primitive equations themselves, and the number of layers in the atmosphere for which data points are plotted has grown.

A six-layer primitive equation model developed at NMC has recently been introduced into the Weather Bureau's operational forecast system. Verification results have been quite encouraging, showing consistent improvement over the previous operational model in the middle troposphere and even more substantial improvement at lower levels. There are notable improvements in the 500-mb. forecast of the trough over the Eastern United States along with associated improvement in the forecast surface frontal position. Research and development work is continuing in order to bring about further improvements in the model. In the past, primary effort has been directed toward the mathematical problems presented by the primitive equation approach. With the attainment of satisfactory solutions to most of these problems, there has been a shift in emphasis to the development of a more comprehensive forecast system—that is, a system that included energy exchange due to radiative, latent, and sensible heat processes, as well as frictional effects. During FY 67, the primitive equation model was refined by including considerations of the latent heat of condensation of precipitation and radiation from snow surfaces.

In the only experiment of its kind attempted to the present, the primitive equation model has demonstrated a capability of producing operational forecasts of some accuracy out to a period of a week. Since the model is still ostensibly short range in character, having only a limited number of energy sources and sinks, better results can be expected with a more comprehensive physical system. To this end, forecast runs past 2 days which include radiational cooling over snow surfaces, modified frictional effects, and latent heat effects are planned for the near future to determine more accurately the extended range capabilities of the model.

Tropical Numerical Prediction Models. With regard to numerical prediction models for the tropics, recent experiments have involved attempts to mesh a tropical belt forecast with a primitive equation high-latitude northern hemisphere forecast to allow high-latitude systems to infiltrate the tropical belt forecast. Although the experiments have only been partially successful to date, it is anticipated that better initial data may lead to usable solutions.

In connection with the tropical analysis program, experiments have been made using satellite cloud data to estimate flow patterns. From these estimates, the "first-guess" stream function for the analysis is modified numerically to reflect high and low centers, jet streams, etc., as deduced from cloud data.

Research on Extended Range Forecasting

Short-range detailed weather forecasting is normally limited to periods of 48 hours in advance. Forecasting for the period from 3 to 7 days in advance is usually called *extended-range*, while predictions still further in advance are called *long-range*. This portion of the report will discuss progress in both extended-range and long-range forecasting by objective numerical means.

Long-Range Forecasting Research. A special study was made of the serious drought situation in the Northeastern United States, linking the lack of rainfall to the weather and circulation in different parts of the hemisphere—especially to the large and persistent anomalies in sea-surface temperature in the Atlantic and Pacific Oceans. A logical outgrowth of this work is the present effort to specify and predict seasonal mean precipitation for several regions within the United States.

Work has continued on the application of a recent thermodynamic numerical model to long-range prediction of mean values of meteorological parameters. Experimental monthly predictions were carried out routinely, using the model during part of the reporting period. The input data to the model were the preceding month's anomalies of ocean temperatures and mid-tropospheric temperatures, as well as the anomalies of the snow boundary. These anomalies are obtained from satellite photographs, which can detect strong anomalies of *surface albedo* (reflected solar radiation). The model predicts the anomalies of temperature in mid-troposphere, at the earth's surface, and the anomalies of precipitation over the Northern Hemisphere.

The model generates internally anomalies of heat of condensation, evaporation at the underlying surface, transport of sensible heat from the surface, and cloudiness. It contains the factors of horizontal transport by turbulent eddies as well as by mean wind.

An attempt to compute the monthly-mean water budget of the atmosphere over the hemisphere from satellite measurements of temperature and cloudiness shows promise of success. Other experiments are directed toward prediction of mean temperatures, winds, and snow cover using satellite data.

Under ESSA contract, a statistical study is being made to predict summer temperatures 1 year in advance. ESSA is also sponsoring a study of the persistence of atmospheric circulation patterns.

Extended Range Forecasting Research. In the area of extended range forecasting, NMC has made a study of the distribution of mean errors of the Weather Bureau's operational numerical 500-mb. forecasts extended out to 6 days. The study was designed to improve the dynamic models by revealing the probable source of error and to provide interim corrections useful in extended range predictions.

Error patterns over the Northern Hemisphere vary with season and type of initial circulation pattern, and are due to shortcomings in the assumptions underlying numerical prediction models. There is strong evidence that omission of heat sources and sinks in earlier models

is responsible for persistent geographically and seasonally oriented errors—a problem which should be materially improved by the use of the primitive equation model. A similar study is being made of a special series of experimental extended range forecasts made using the new primitive equation model.

The catalog of 5-day mean 700-mb. height anomaly centers completed during FY 65 has been published and is being used for further extended range forecasting studies. These data are used to determine the probability of different types of mean temperature and precipitation anomalies for various regions at different seasons of the year. A method for selecting analogs corresponding to 5-day mean 700 mb. height anomaly charts has been developed and is being used as an aid in operational forecasting. Such analogs are selected from an historical file by high-speed computer and then examined for their resemblance to a given situation with the aid of a microfilm reader.

Statistical Forecasting. The derivation of objective forecasting equations for 5-day precipitation amounts for regions of the conterminous United States has been completed for all seasons and the system put into operation. These equations were also adapted for use in specifying monthly precipitation from mean monthly 700-mb. prognostic charts.

TDL also performed applied research directed toward making practical use of numerical prognostic charts in forecasting storm surge produced by extratropical or winter-type cyclones. An objective method has been developed in which sea-level pressures at several NMC grid points from 0 to 24 hours in advance are used as predictors, and the forecast equations are derived by the multiple regression screening procedure. The results of this method at Atlantic City compare favorably with those of earlier studies, and equations are now being derived for other locations along the east coast of the United States.

Wave and Seiche Forecasting. The ocean wave forecasting system used by the Navy's Fleet Numerical Weather Facility is being adapted by TDL for Weather Bureau use. Wave forecasts will be based on the 1,000-mb. winds forecast numerically at NMC. It is expected that the method will become operational about the middle of FY 68. After that time, effort will be devoted to further adapting the system to NMC meteorological inputs.

Network Density. Experiments in network density have sought to determine the following:

a. The manner in which variations in density of observations of a regular array of perfect observations affect the error field in hemispheric forecasting;

b. The manner in which errors in the observations affect the above results;

c. The effects on the error field resulting from the uneven distribution of observations;

d. The extent of diminution of the error fields resulting from various augmentations to the present network, especially over oceanic and desert areas;

e. The extent to which very dense networks over continental areas like the United States are vitiated by oceanic areas of comparative data void;

f. The possibility of exchanging frequency for density of observations; and

g. The extent to which meteorological satellite systems, such as superpressure balloons monitored by satellites, can be used to augment conventional networks, and the manner in which these systems are best incorporated in a unified scheme suitable for hemispheric or global numerical prediction.

During FY 67, the first phase of the series of experiments to determine optimum networks for the World Weather Watch was completed, using the barotropic mesh model and assuming a regular lattice of perfect observations. It indicates that, for the purpose of numerical prediction by the barotropic model on a hemispheric scale, there is little point in having aerological observations closer than about 600 or 700 miles. The experiments also indicate that the present nonhomogeneous distribution of aerological stations is highly inefficient. The above results will be included in the relevant WMO Planning Report for the World Weather Watch.

In the second phase of this project, identical experiments were performed with the barotropic model and with the primitive equation model. In general, results from this phase confirm previous findings but indicate that the primitive equation model is somewhat less sensitive to network deterioration than the barotropic model. Further experiments will be conducted with the Geophysical Fluid Dynamics Laboratory (GFDL) model as a reference atmosphere.

Experiments with random errors superimposed on grid-point values of the experimental networks revealed the possibility of exchanging station density for accuracy of observations. For instance, it was found that a network with stations 500 km. apart and root-mean-square random errors of 12 m. is equivalent to a network of stations 850 km. apart but with root-mean-square random errors of 8 m. and to one with perfect observations 1,350 km. apart.

A contract was completed during the reporting period on the effect of varying data density on objective analysis of surface wind in the tropics. The study was extended to include selected cases at 500 mb. and a report was prepared during FY 67.

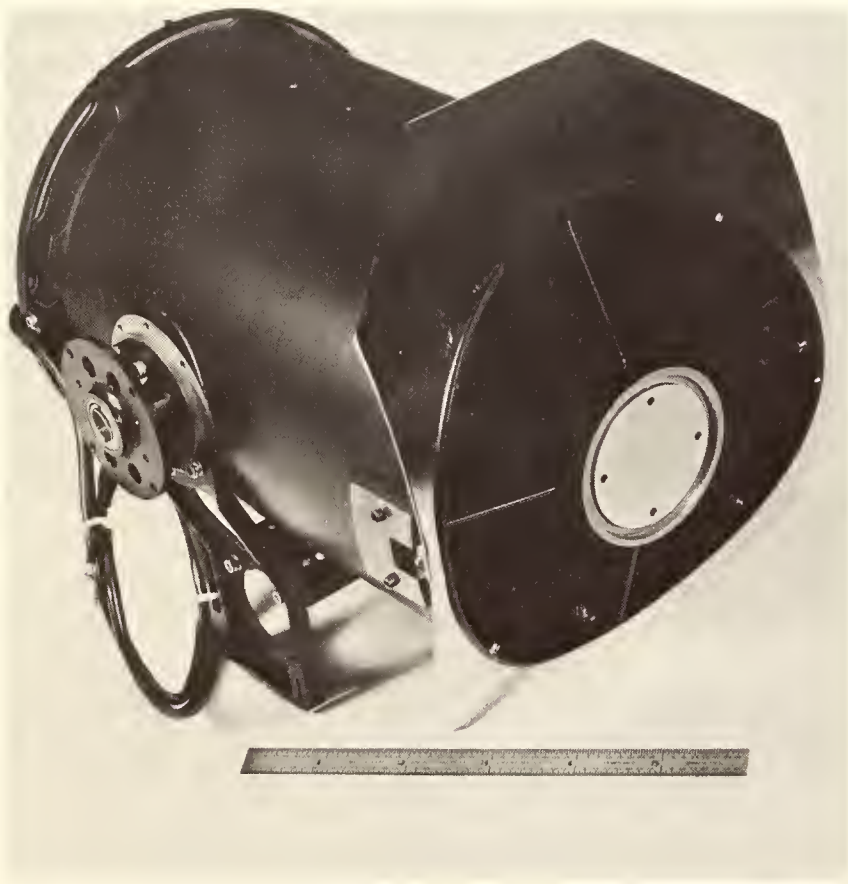
A preliminary plan for assessing network requirements in the tropics was prepared. All possible sources for data pertinent to this project are being tapped to enable accurate computation of the requisite time and space correlations. In conjunction with these various network studies, a new contract has been negotiated to apply information theory to the study of network requirements.

Satellite Meteorological Research

The primary objective of the National Operational Meteorological Satellite Service (NOMS) is to establish and operate satellite systems to meet the following three requirements:

1. Regular and reliable viewing of the atmosphere over the entire globe;
2. Continuous viewing of weather features; and
3. Regular worldwide sounding of the atmosphere.

TOS System. The coverage provided by the ESSA satellites of the Tiros Operational Satellite System (TOS) meets the first requirement to a limited extent. While the daylight portion of the earth is regularly photographed, the nightside is not observed. Infrared sensors will be adapted to TOS system satellites to provide this coverage. In addition, an improved TOS (ITOS) satellite, will be launched by NASA in 1969. This Improved TOS will carry combined Automatic Picture Transmission (APT) and tape storage cameras, an infrared radiometer system, a proton counter, and other instruments.



The ATS Spin-Scan Cloud Camera.

Continuous observations of the earth and its atmosphere to meet the second objective can probably be acquired most economically by a system of satellites in earth synchronous orbit. Such a satellite system is being studied and technically defined to meet this requirement, as well as that of the data collection and relay. The spin-scan camera, which may be used in this system, has been successfully tested on NASA's Advanced Technology Satellite (ATS–1).

Satellite Infrared Sensors. The means of achieving the third objective—obtaining global measurements of the vertical distribution of temperature, humidity, ozone, or other atmospheric parameters—is currently under study. During the reporting period, instruments were in the process of development to obtain some of the needed measurements, while other instruments to obtain additional measurements were being investigated. SIRS, which was successfully balloon tested, is nearing flight readiness for test on NIMBUS B. It will measure the vertical temperature structure of the atmosphere and the horizontal distribution of water vapor in the atmosphere. An alternate instrument, the Infrared Interferometer Spectrometer (IRIS), is also being developed by NASA to acquire these measurements. Measurements of the height of cloud tops will be acquired with the SIRS or IRIS system or with the oxygen "A" band spectrograph.

In a parallel effort, an instrument is being developed to measure the vertical distribution of atmospheric ozone by measurement of the scattering of solar ultraviolet. Also under consideration are instruments to measure sea and land surface temperatures in the microwave region of the spectrum.

During FY 67, emphasis was placed on the study of the water vapor rotation bands. Water vapor spectral intervals to be examined with SIRS-B have been chosen, and transmission functions have been developed. Calculations of rotational water vapor band absorption show agreement with laboratory absorption curves. Other studies measuring radiation were made in the 7600 Å and 6 and 10 micron bands. The study in the oxygen band at 7600 Å was completed and the results have been incorporated into atmospheric transmittance calculations. A new model, SIRS-IV, is under design and has been accepted by NASA for the NIMBUS D satellite. SIRS-IV will measure the vertical distribution of atmospheric water vapor over a wider geographical region.

Data Relay. Current and planned system spacecraft are being considered for use as collectors and retransmitters of raw and processed environmental data. Systems for interrogating, recording, and retransmitting data from ground-based or airborne observation platforms are under development. The IRLS (Interrogation, Recording and Location System) would permit the satellite to contact remote platforms such as constant level balloons, buoys, or automatic weather stations; command a readout of their data; fix each station location; and then retransmit the collected data to processing centers remote from the observation platform.

Cloud Studies. Several synoptic investigations are in progress at the NESC Meteorological Satellite Laboratory (MSL) to increase skill in interpretation and understanding of meteorological satellite data covering jet streams, cyclones, clear air turbulence, secondary cloud spirals, etc. Satellite cloud pictures have been used to estimate the location of mid-troposphere trough and ridge lines. The resultant data is prepared for input to NMC where it is used as an aid in the analysis of Southern

Hemisphere patterns. Satellite pictures of cirrus orientation, cloud length and continuity are being used to determine wind stream speed and direction in the tropics. These data are being used as inputs to the numerical analysis being prepared by NMC. They are also transmitted to other offices requiring upper level tropical data.

Much attention has been focused on the jet stream. One study shows that jet streams can be reliably located whenever clearly defined cirrus layers, terminating abruptly on the poleward edge, appear in the pictures. This inhouse study and another performed jointly with Colorado State University suggest that these cloud characteristics may sometimes define the jet stream position more accurately than conventional data, even in regions considered relatively rich in data.

In the study of cyclones, Project STORM CLOUD has produced an unusually detailed case study of an East Coast storm by combining data from many and varied sources such as: Regular and special rawinsonde reports, surface reports, radar, instrumented weather aircraft, commercial aircraft, time lapse film photographs, and satellite pictures. The project report demonstrates the complementary value of one data source to another in obtaining a detailed description of the atmosphere.

Many secondary cloud spirals appear in satellite pictures, particularly over oceans. Some appear to be terrain-induced, others are thought to be related to wave development on fronts, and still others appear to have developed into major cyclones quite independent of frontal systems. An MSL project is in progress to determine the true nature of these spirals.

During FY 67, it was found that sensible heat from ocean surfaces appeared to have little or no effect on secondary cloud spirals. This was surprising in view of the preference of these systems for oceanic areas and because of the presence of many cellular cumulus clouds indicating heating from below.

The availability of satellite data also makes possible new studies of various atmospheric mechanisms, a number of which are progressing at universities and other research institutions under ESSA sponsorship. For example, in FY 67, the Environmental Data Service began publishing daily computer-generated photographic cloud mosaics of both the Northern and Southern Hemisphere in its *Catalog of Meteorological Satellite Data*. The Catalog produces an index of television cloud photography by the various ESSA satellites. Beginning with the current issue (ESSA 3, Part 2) each number will cover a 3-month period. The mosaics replace the hand-drawn nephanalyses of previous issues and are generated operationally at NESC.

Radiation Studies. During the reporting period, construction of monthly mean charts of outgoing long-wave infrared radiation from the earth for the months of July 1963–May 1964 using TIROS VII data have provided the longest series of such data on this scale ever available. The charts for the months of February–May 1964 were compared with those for the same months in 1962, previously constructed from TIROS IV data. Although there are many similarities between the same months for the 2 years, the differences between them average about 5 percent, with maximum differences ranging up to 30 percent of the mean values of radiation. Further observations of these planetary scale variations in radiation from one year to another may lead to new knowledge about the control that changes in heat sources and circulation in one hemisphere may exert on the heat sources and circulation in the other hemisphere.

Combined use of long-wave radiation data and cloud cover information from satellite pictures over 15-day periods has allowed for comparison of variations in the location of the Intertropical Convergence Zone (ITC) over 3 years in the months of February and March. This Zone, which represents the meeting place of winds from the two hemispheres, is of considerable importance in the understanding of tropical meteorology. Since the behavior of the ITC is most typical over the ocean areas where surface data are not available, satellite information is particularly important. It has been found that the ITC shows the greatest persistency of location in these months from one year to the next over the Atlantic and eastern Pacific and the most pronounced variations south of the Equator over the Indian and western Pacific Oceans. During the reporting period, research was conducted to relate these variations to the strength and location of the convergence of the wind field in the tropical regions, as well as to deduce the role of circulation and heat balance of the temperate zones of both hemispheres on ITC.

While circulation essentially controls cloud distribution and therefore radiative heat sources, the heat sources in turn may have some influence on the circulation. In particular, the north-south variation in radiative heating affects the generation of zonal available potential energy since it partially determines the thermal gradient between high and low latitudes. Calculations of the contributions of the net radiation to energy generation during the February–June 1962 period indicated that generation of zonal available energy does indeed vary with the state of the circulation itself. There is a higher generation of energy when the westerlies are strong and weaker energy generation when the westerlies are weak. In the latter case, the flow is broken down into a predominantly cellular pattern, and the available potential energy is low. Earlier tests using the first general circulation computer model developed by GFDL indicated that such heating variations could have substantial effects in amplifying and prolonging energy cycles in the atmosphere. The more comprehensive data coverage that may become available from the NIMBUS II satellite and future polar orbiting satellites should provide for more detailed studies of this mechanism and its effect on the world's weather.

Operational Applications. Pictorial data received from operational ESSA satellites show the distribution of cloud amount, the patterns and formations which clouds take, and how these evolve from day to day. Operational meteorological analysis today deals primarily with the

fields of wind, pressure, humidity, and temperature. Thus, to apply satellite data to operational analysis, it is necessary to be able to make reliable inferences from the clouds concerning the fields that have produced them. In particular, if satellite data are to be of maximum value to the meteorologist, it must be possible to make such inferences in data-sparse areas where no direct measurement of these parameters is available. Thus, a major objective of NESC, through its Applications Group, is to continue to develop models which relate certain recognizable patterns of cloud organization to familiar synoptic scale flow-patterns and processes, in the same manner as has already been done with hurricanes.

Studies based upon satellite pictures received from TIROS I through VIII identified the cloud formations produced by large-scale cyclonic storms, fronts, the jet stream, and upper tropospheric pressure troughs. They also showed that it is possible to identify reliably, in the satellite photographs, cloud forms such as cumulonimbus, cumulus congestus, strato-cumulus, stratified middle cloud, and several forms of cirrus. Further, it has been shown that it is possible in some instances to estimate shear, and the low-level wind speed and direction from the appearance of the medium scale (mesoscale) cellular and banded patterns of the clouds.

The global coverage provided by TIROS IX early in 1965 made it possible for the first time to observe daily the development and evolution of the cloud formations associated with synoptic scale circulation systems. By combining these new data with the results of previous studies, it has been possible to formulate synoptic scale cloud models that show the relationship between cloud patterns and the wind field in both the lower and upper troposphere. The models also depict the comma-shaped cloud formation which is produced by the circulation around the concentrated low-pressure zone associated with a cyclone, and the relationship of these vortices to a developing frontal wave. Over the oceans, where conventional data are sparse, it is often difficult to identify and locate such cyclones, but the distinctive cloud formations which they produce now make their identification straightforward from satellite pictures. Applying this type of cloud model, some aspects of surface and upper air circulation may thus be directly interpreted from cloud form and distribution. Additional models are being developed using ESSA I data that relate to other specific synoptic situations, with special emphasis on tropical cloud models.

Hurricanes and Severe Storms

Because hurricanes are a phenomenon of the marine environment, and tornadoes and severe local storms are of primary concern over the land areas, research in this area in ESSA is divided between hurricane studies and those involving other types of severe storms. NHRL at Miami, Fla., and NSSL at Norman, Okla., both elements of the Institute for Atmospheric Sciences, have primary responsibility for those two areas. Other elements of the Institute, such as GFDL at Washington, D.C., APCL at Boulder, Colo., and RFF at Miami, also participate in this research. Major contributions are also made by IO, NESC, and elements of the Weather Bureau, particularly the National Meteorological Center and TDL.

Hurricane Research. The hurricane as a phenomenon of the air-sea interface cannot be studied in isolation, that is, apart from the base state of the tropical atmosphere and the other types of perturbation which may take place within it. Consequently, NHRL is engaged in studies of other tropical cyclones, easterly waves, upper-level cold vortices, etc., with the following major objectives:

(1) Improvement in the prediction of formation, motion, and change in intensity of hurricanes and other tropical cyclones.

(2) Improvement in the prediction of the coastal water levels to be expected when a hurricane strikes a coastal area.

(3) Increased understanding of the physical processes that govern the life cycle of hurricanes and the ultimate development of a theoretical model which will simulate the hurricane in all of its phases.

Six tropical cyclones, with four reaching hurricane intensity, developed over the tropical Atlantic during the FY 66 hurricane season (June–November 1965). Except for five during the 1962 season, this was the smallest number since 1946. During the past 30 years, the average has been approximately 10 per year. The major factors contributing to the below-normal hurricane activity seemed to be the cool temperatures in the tropics and the unfavorable general circulation which developed in September 1965.

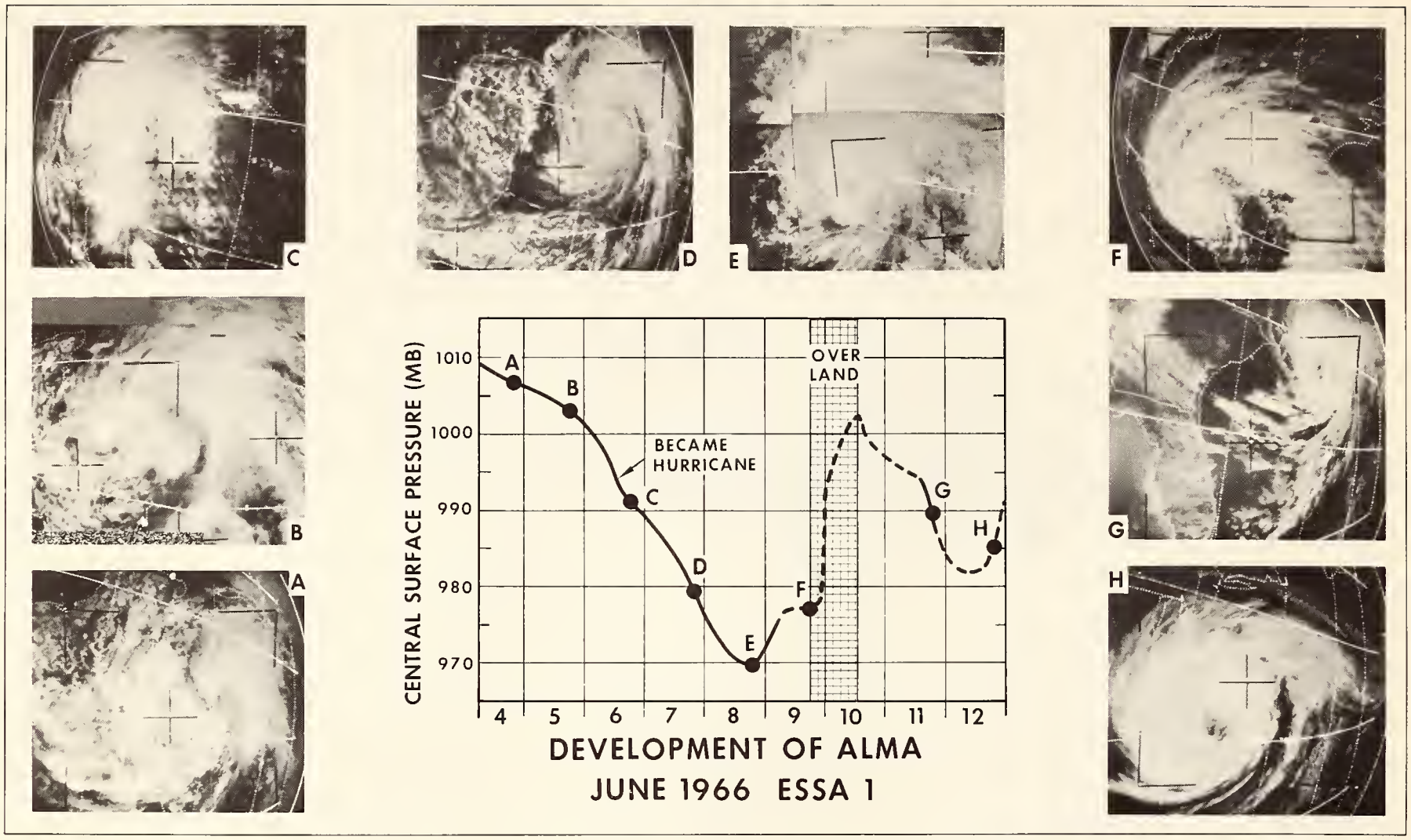
Of these four hurricanes, only BETSY made landfall, or came within reach of an RFF aircraft, first striking the Bahamas and southern Florida and later the north-central Gulf of Mexico coastal area. The enormous amount of damage produced in the latter area made BETSY the most destructive hurricane on record. While damage in Florida was not as great as that attributed to DONNA (1960) and DORA (1964), damage from BETSY in Louisiana alone far exceeded that of any other hurricane. Even adjusting for the increased property valuation over the years, the damage by BETSY probably equals or exceeds that attributed to any other major disaster of all time.

A number of penetrations were made and extensive reconnaissance was carried out on BETSY during her slow course from the Lesser Antilles to the Florida Peninsula. DEBBIE promised some hope that it would be possible to document the transition from tropical storm to hurricane. However, the storm never did acquire hurricane intensity so that the immediate value of the data gathered was considerably eroded by the lack of further data depicting a deeper phase. During FY 67, no hurricanes were in an area considered suitable for experimentation.

A Research Flight Facility DC-6 in flight (foreground), with a W-57 aircraft in the background. The DC-6 aircraft are heavily instrumented for the measurement of atmospheric conditions associated with storm systems, as are the W-57's, which have a greater ceiling (up to 40,000 feet) than do the DC-6's. (Left) The heavily instrumented interior of a typical RFF DC-6.

Because of the small amount of hurricane flying which the seasons afforded, RFF, along with various other agencies studying hurricanes, devoted considerable effort to other projects in tropical meteorology of a more general nature. The largest of these was Project ECCRO (Eastern Caribbean Cooperative Reconnaissance Operation) which studied winds and other meteorological parameters at a number of altitudes over a broad area for several days.

The Meteorological Satellite Laboratory of NESC has been examining the use of satellite data as a tool for tropical weather analysis. Many distinctive cloud formations appear in the tropics, the most significant of which show hurricanes and typhoons. Studies relating wind speeds and stage of development of hurricanes to cloud pattern in the satellite pictures continue and have been expanded to include patterns in the infrared radiation data. Finally, case studies of hurricanes BECKY (1965) and ALMA (1966) are in progress to verify a theory of hurricane formation based on the conservation of angular momentum.



The development of Hurricane Alma, June 1966, as photographed by the ESSA I satellite. The development of the hurricane is compared to a plot of the barometric pressures as measured at the central surface.

Based upon data obtained from aircraft, satellites, and surface and upper air observations, an extensive program of theoretical study under ESSA sponsorship seeks to identify the causes and origins of tropical storms and hurricanes; improve predictions of their formation, motion, and effects; and provide data for use by scientists studying the possibility of moderating the violence of such storms.

For example, one NHRL study revealed that contrary to the behavior of the atmosphere observed in temperate zones, the relationship between pressure patterns and wind fields is not straightforward for tropical zones, and, in fact, is too complicated to be represented pictorially. It has been found that quite different flow patterns can be associated with very nearly the same pressure pattern. This fact has important ramifications to operational weather analysis in the equatorial zone. One such implication is that the construction of a pressure chart (even one of perfect accuracy) gives very little information concerning the field of motion if it is only subjected to visual inspection. Furthermore, if subjective, hand techniques of analysis are to be relied on, it appears that the field of motion in equatorial analysis can be established only by direct analysis of the wind reports. Therefore, to employ pressure reports as an aid in this analysis, most likely machine techniques will be required because of the complexity of the wind-pressure relationship.

Studies are also being conducted to determine interactions between the tropical cyclone and its environment in efforts to determine the factors involved in hurricane formation, intensification, dissipation, and movement. Tropical cyclogenesis and maintenance are being studied by the development of dynamical-numerical models of tropical circulations.

At the same time, work continued on the further development and refinement of a new, statistical-climatological model for forecasting hurricane motion. Verification statistics from past cases of forecasts by the revised equations revealed forecasts by the model to be superior to the forecasts by subjective hurricane forecasters. Theoretical studies have defined many details of the wind-pressure relationship at low latitudes and have greatly increased the understanding of the development and maintenance of perturbations in equatorial zones.

Tornadoes and Severe Local Storm Research. Tornadoes and severe thunderstorms pose a major threat to many sections of the United States. To study and to improve its capability to predict their formation and behavior,

NSSL conducts a specialized research program using a unique and highly instrumented ground network at Norman, Okla., in conjunction with aircraft flights by the RFF, the Air Force, and other agencies.

Improved bases for analysis and prediction of severe storms have been developed at NSSL. Radar shows that storms with different structures occurring near each other at the same time may move in markedly different directions. It is, therefore, practically impossible for an operator to stay abreast of the rapid developments characteristic of the most severe and important situations. However, new techniques of radar data processing demonstrate the feasibility of defining the separate motions accurately and speedily for application in the operational radar system.

A study of the properties and extent of in-flow of moist air to a severe storm has shown that about 60 percent of the moisture condensed and descended as rain. The convergence of moisture over state-wide areas can be deduced from surface network measurements and upper air soundings some hours in advance of severe storm developments. Advanced radar data processing techniques now provide more accurate measures of precipitation associated with a storm.

NSSL has evaluated the most recent severe storm model concepts by small-scale laboratory experiments in fluid dynamics and by measurements and study of radar scope patterns of attendant precipitation. The theory of tornadoes is exceedingly complex, and it is apparent that useful development of the theory needs the inspiration of direct measurements of real tornadoes and the output from a realistic model. The model studies conducted by the Laboratory during the reporting period have indicated that at least one likely pattern of local wind not heretofore considered can be extremely important in the development of the tornado.

In TDL, the Weather Bureau work is continuing on the development of an operational model for prediction of selected parameters related to severe storm occurrence. A computer program has been completed to generate three-dimensional trajectories utilizing output from the NMC primitive equation model. It is anticipated that this task will provide improved prognostic soundings and measures of atmospheric stability. During FY 67.

The hookline configuration of a radar echo indicates a heavy thunderstorm with which a tornado is usually associated.

TDL also granted a research contract to develop improved techniques for forecasting severe convective storms and their associated hazards. The objectives include study and evaluation of present forecasting techniques, development of improved diagnostic procedures, and development of more accurate forecasting techniques. All analysis and forecasting techniques will be prepared in a form which can be programed for computer use in actual forecast operations.

Aircraft Storm Hazards. NSSL during FY 67 launched a study of the relationship of storm hazards to aircraft safety. The objective of this project is to develop more accurate descriptions of thunderstorm hazards to aviation and to devise techniques for the improved use of storm forecasts and detection equipment.

The heights of cloud tops above 40,000 feet recorded during 1962 and 1963 by photography from a U–2 aircraft, were measured and related to other meteorological features. Additional flights by RB–57F aircraft in the spring of 1967 observed higher tops than those found in 1962 and 1963.

A program involving the cooperation of several agencies of the U.S. and British Governments, with overall management provided by NSSL, has yielded new knowledge of the structure of turbulence in and near thunderstorms. A quantitative description of statistical properties of in-storm turbulence in relation to radar echo signatures has been given and several cases of severe clear air turbulence near thunderstorms have been documented.

Turbulence and temperature variations in clear air near the tops of large thunderstorms were studied with the assistance of aircraft and staff of the British Royal Aircraft Establishment. Turbulence over thunderstorms above 50,000 feet was recorded in 1967 during flights by RB–57F and U–2 aircraft of the USAF.

Lightning hazards to aircraft have become evident from investigation of several recent incidents in which severe effects of lightning strikes on aircraft have been found. A satisfactory assessment of the characteristics and distribution of lightning in the vicinity of severe storms is therefore desirable for improving the safety of flight operations. A technique for lightning location based on measurements of electrostatic field changes at different locations was analyzed. The report concluded that an effective lightning location system based on such measurements can be realized with a minimum of four stations.

New measurements at NSSL indicate that the range of nighttime lightning can be determined from arrival times at a single station, of direct radiation and successive orders (up to six) of E-layer ionospheric reflection. Analysis of these times of arrival and the simultaneous signals from directional loop antennas may determine areas of lightning activity suitable for incorporation in the correlation studies. NSSL, in another phase of this project, is looking into the feasibility of obtaining correlations which would yield statistically reliable assessments of relationships between storm dynamics and electricity.

The technical feasibility of exploiting different features of electrical signals produced by lightning in order to locate and follow areas of lightning and assess its severity has been explored by NSSL. This has led to a contract for the development of an operational system to provide airline meteorologists and operators with instantaneous knowledge and displays of lightning over a range of 100 miles from centers of operation.

A radar attachment has been developed which greatly increases the speed and accuracy with which radar data can be displayed. Simultaneously, it facilitates automatic processing of weather radar data for rapid automatic transmission of interpretative information via standard land lines. This prototype device is now in routine use at NSSL and engineering work is underway to provide a version suited to general field operations.

During the reporting period, digitized radar data was transmitted from NSSL to the Weather Bureau's River Forecast Center at Fort Worth. This was a highly encouraging first experiment to evaluate techniques for combining high-speed digital computers and comprehensive radar data in an operational program of flood warning and water resources management.

Finally, significant advances have been made in developing Doppler radar as a meteorological observing tool. The feasibility of observing details of wind structure within 5,000 feet of the ground on many clear days has been demonstrated. One study treats the structure of a low-level jet stream associated with large, height-dependent wind variations which pose an operational problem for aircraft during takeoff and descent. Improvements in radar design suggest that a number of Doppler radars could be provided at relatively small cost to give more comprehensive definition of wind fields accompanying storms and to monitor the wind profile at air terminals.

PREDICTING THE INTERACTION BETWEEN THE ATMOSPHERE AND THE SOLID EARTH

Completing the hydrologic cycle which starts at the sea-air interface is the interaction between the atmosphere and the solid earth—the partial return of moisture which originated in the sea to its origin through precipitation and runoff. Predicting this interaction and its results in the form of drought or flood is a key ESSA program.

River and Flood Prediction and Warning

River forecasting consists of four major steps: (1) The determination of the amount of rainfall or snow melt over the area draining into the river; (2) the estimation of the amount of water which runs off the drainage area into the river; (3) the determination of the rate at which water reaches the river; and (4) the prediction of the changing shape and speed of the flood wave as it moves downstream. (After the water has run off into the river, it assumes the shape of a wave, with the water level rising and then falling at every point along the river as it is passed by the wave.)

The most severe problems in river forecasting include: Achieving a maximum forecast accuracy while giving adequate warning time, sampling the precipitation in sufficient detail over a large enough area, and accounting for the effects of storage and delays of water in flowing over and through the soil to the river. High-speed computers assist in attacking these problems by speeding up the data reduction and analysis process and accommodating much more complex calculations than were possible before computers became available. Research is continuing on the development of a water accounting model making use of the Modified Stanford watershed model. Research is also being continued on the modification of the Antecedent Precipitation Index forecasting model currently used operationally by field offices, with the major effort during FY 67 being devoted to a method for generating a continuous hydrograph of total runoff.

An important influence on the role of the soil in the rainfall runoff process is the effect, between rains, of evaporation from the soil, and transpiration of moisture from plants growing in the soil. Studies of evaporation are necessary for evaluating transpiration, and also are important for estimating water loss from lakes and reservoirs. Comparisons are being made of evaporation utilizing special steel tanks at a variety of locations including Virginia, California, Arizona, and Nevada. New experimental insulated pans are being tested in these areas as well as in Washington, D.C.

In planning and designing dams and other water management structures, an essential step in determining design capacities is the anticipation of the magnitude of storm runoff to be accommodated. For small structures, such as urban storm sewers and culverts, it is customary to design for a storm or flood which would be equaled or exceeded, for example, once in 10 years. For spillways of larger dams, the failure of which would endanger human life or cause substantial property damage, the design is usually based on the maximum rainfall that can reasonably be expected.

Organization and Facilities

ESSA's service and research programs in hydrology are performed by the Weather Bureau's Office of Hydrology, located in Washington, D.C. Research data are obtained from the networks of hydrological and meteorological stations which exist for the service program. Research is also performed at a number of field locations by both ESSA and contractor personnel, and modern computer facilities are available for data analysis and theoretical computations. Development and test of instruments and equipment for hydrology are performed for the Office of Hydrology by the Equipment Development Laboratory (EDL) at Silver Spring, Md., and the Test and Evaluation Laboratory at Sterling, Va., both elements of the Weather Bureau's Systems Development Office.

Instrument and Systems Development

A number of new instruments and systems were ready for field testing during the reporting period including the following:

Digitized Radar Precipitation Data. The system for transmitting digitized radar precipitation data directly to River Forecast Centers developed jointly by the Office of Hydrology and the National Severe Storms Laboratory is continuing to be evaluated by NSSL and the Weather Bureau's Fort Worth River Forecast Center. Broader field evaluation will follow this phase.

Telemetering Storage Precipitation Gage. Seasonal precipitation storage gages are an important means of assessing the runoff potential of snow fields, particularly in the western regions of the United States. Many of these installations have in the past been accessible only with great difficulty during the winter months. To make data from the gages readily available to hydrologists, Equipment Development Laboratory developed an electrical readout with an accuracy of one-tenth percent for measurements up to 5 inches and 2-percent accuracy for measurements above 5 inches. It is equipped with radio telemetry components so that gage readings can be obtained instantly by radio interrogation. Currently available sensing and telemetry components were adapted to the system where possible. This system was field tested during FY 67.

Flash-Flood Alarm. Many communities in headwater areas are susceptible to damage and loss of life from flash floods which occur when heavy local rains suddenly cause streams to rise and inundate inhabited areas before normal data collecting and flood forecasting facilities can detect the situation and issue warnings. Equipment Development Laboratory has developed a device to sense these sudden, dangerous rises in streams and to sound a warning to local residents. It consists of a level detector for location upstream of the community to be protected which is connected by radio or telephone line to a visual and audible warning device located in a firehouse, police station, or residential area. The device is now under operational test by the Test and Evaluation Laboratory.

Solar Radiation Measurement. The measurement of incoming solar radiation is of primary interest in evaporation, snow melt, and general hydrologic cycle studies. At present, the small number of observation stations severely limits the use that can be made of daily solar radiation information. Equipment Development Laboratory has developed an instrument that will allow large-scale extension of the present network at modest cost. The device, a portable, self-contained solar radiation integrator, is essentially an inexpensive water calorimeter that stores heat energy throughout the day. It is designed to maintain its calibration for long periods with day-to-day accuracy of 10 percent or better.

Research in Hydrology

Research at the Office of Hydrology falls into two broad

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categories: Studies of the hydrologic cycle with particular attention to improved river forecasting, and precipitation climatology studies directed toward developing information of value to engineers and water-management authorities.

River Forecasting Studies. Research is continuing on the development of a mathematical model of the hydrologic cycle to permit increased automation of river forecasting and increased prediction accuracy. The current phase involves adding to the model details of the soil phase of the cycle: Snow pack, impervious contributing areas, evapotranspiration, several layers of soil and ground water storage, and flow. A number of experimental and theoretical studies are being conducted in support of this model development.

For example, the effects of physiographic environment on evaporation have been observed at Farmington, Utah, and analysis of data is underway. An improved technique has been developed for computing lake evaporation from air temperature, dew point, wind, and solar and long-wave radiations. Using the new knowledge and data collected over a 10-year period, evaporation maps for the United States are now being updated.

A snow research project is being carried out with the Agricultural Research Service at the Sleeper's River Watershed near Danville, Vt. A meteorological station has been established to measure the meteorological factors involved in the energy budget of snow melt. A member of the Office of Hydrology staff has been assigned on a full-time basis to make observations and maintain equipment. The Sacramento River Forecast Center, in cooperation with the California Department of Water Resources, is conducting research on the use of *snow pillows* at Twin Lakes in the American River Basin. These devices are rubberized canvas or plastic bags filled with low-freezing-point liquid which open into a manometer tube for measuring the pressure of the snow over-burden, thereby determining the water equivalent of the snow pack.

There has been much interest recently in the use of satellite photographs to determine snow cover for hydrologic purposes. While some use can be made of ESSA satellite data, improved resolution and dynamic range will be required in future systems before widespread analytic use can be made of this new technique for hydrology. For accurate estimation of potential runoffs, some means of determining water content of the snow by relay of *in situ* data will also be required. An initial contract to continue the work has been let. Studies of possible future techniques are underway.

Precipitation Climatology. Studies of precipitation climatology cover both the extreme and average values to be expected. Typical studies of extremes included: Estimates prepared for the Corps of Engineers of probable maximum precipitation and snow melt conditions over several Midwest river basins, including the South Platte in Colorado and the Minnesota River; estimates of probable maximum precipitation and rainfall intensity-frequency prepared for proposed canal routes through Panama and Northwestern Colombia; studies of probable maxima over the Rio Grande Valley for the Soil Conservation Service and the detailed study of the severe rainfall patterns associated with Hurricane Betsy in the Mississippi Delta area. The Soil Conservation Service is sponsoring the preparation of detailed physiographically adjusted rainfall frequency maps for the western United States for 6- to 24-hour amounts for return periods of 2, 5, 10, 25, 50 and 100 years. Maps for Arizona and New Mexico have been completed.

The Corps of Engineers has been sponsoring river basin studies since 1937. These studies include estimates of probable maximum precipitation and, where appropriate, optimum snow melt conditions. Reports of such studies published during the reporting period include such diverse areas as the Susquehanna River; the Yukon River; Takatz Creek, Alaska; St. Johns River, Maine; Minnesota River; South Platte River, Colo.; and the Delaware River. Similar studies were also conducted for the Tennessee Valley Authority for the Tennessee River Basin above Chattanooga, Tenn.

With respect to typical or average rainfall patterns, studies have encompassed the following: Continuing study for the Geological Survey of the precipitation regime of Long Island, including frequency, seasonal, and other relationships in support of a water resources survey; detailed seasonal and annual precipitation maps for the 15-year period 1951–65, including frequency distributions; a study for the Soil Conservation Service of the average number of days of per month with precipitation of .5, 1.0, 2.0, 4.0 inches or greater; the preparation of daily maps of selected major storms and physiographically adjusted rainfall intensity-frequency maps for the Western United States; daily maps of rainfall depths in the Wabash River Basin; and studies of storm rainfall in the upper Colorado River Basin in support of a weather modification investigation by the Bureau of Reclamation. The latter studies included typing with respect to season, atmospheric circulation, and physiography.

PREDICTING THE TELECOMMUNICATIONS ENVIRONMENT

Although telecommunications primarily utilizes the atmosphere and the ionosphere, all elements of the environment are used, at least to a degree. Variations in environmental parameters cause variations in propagation conditions and hence telecommunications prediction is to a large extent concerned with the forecasting of environmental change. Programs in this area support ESSA's telecommunications services and, in addition, bear indirectly on most other program areas in view of the importance of telecommunications in data acquisition and dissemination.

Research in Telecommunications Prediction

While ESSA's interest in telecommunications extends across the usable electromagnetic spectrum from 1 cycle per second to 10^{15} cycles per second (Hz), the day-to-day

service program in real-time telecommunications prediction is presently limited to those frequencies affected by the presence and position of the ionosphere, i.e., from Extremely Low Frequencies (ELF) to about 3×10^7 Hz. Frequencies higher than these are affected primarily by atmospheric factors and will tend to become predictable in their behavior in the same measure that weather becomes truly predictable, particularly with regard to humidity and atmospheric noise. Consequently, real-time prediction activities may be expected to grow in the future.

To an extent, research in support of present and future service programs in telecommunications prediction also supports programs in telecommunications engineering; however, where the primary emphasis is on the effects of changing environmental factors, it will be reported in this chapter. Fields to be discussed include: Ionospheric propagation, tropospheric physics, and radio meteorology.

Organization and Facilities for Research

Research, development, and engineering as well as services in telecommunications in ESSA are the responsibility of the Institute for Telecommunication Sciences and Aeronomy (ITSA). Activities are divided between the Ionospheric Telecommunications Laboratory (ITL), which is primarily concerned with propagation at frequencies from 1 Hz to 3×10^7 Hz, and the Tropospheric Telecommunications Laboratory (TTL), which is concerned with Very High Frequency (VHF) and higher frequencies up to the optical range.

ITSA's Laboratories at Boulder, Colo., are unusually well-equipped for the study of all aspects of telecommunication prediction, with data available from a worldwide ionosonde network and other global sources. Ionospheric predictions are prepared by ITSA for military and civilian radio services, satellite, missile and space programs, as well as for other scientific and engineering applications. At the same time, research and development is conducted on improvement of methods of ionospheric predictions, and on the application of predictions to the requirements of specific problems of national importance. Field experiments are also conducted by ITSA personnel at a variety of locations.

Instrument and Systems Development

As in any type of research, considerable equipment and apparatus are developed as an integral part of experimental research programs. In addition, telecommunications engineering programs develop antennas, transmitters, and receivers which are useful in propagation studies.

In ITL, a new model ionospheric sounder is under development, incorporating features affording increased flexibility and accuracy. The output data are adaptable to automatic data processing. This sounder will become a tool for the telecommunications prediction service program when its development is complete.

Ionospheric Propagation Studies in the ELF-MF Range

This program covers research in radio propagation from the ELF to the Medium Frequency (MF) range. The frequencies covered are from 1 Hz to 3×10^6 Hz, almost seven decades. In this range, propagation is affected by both the earth and the ionosphere. Together the two form a type of waveguide at certain frequencies which conducts signals for great distances, making the lower frequencies in this area of considerable importance for long-range telecommunications, particularly during ionospheric storms, which may temporarily obliterate other usable portions of the spectrum.

This region of the spectrum is used for communication with submerged submarines, the detection of high-altitude nuclear explosions and solar proton events, long-range navigation systems, transmission of frequency and time standards, and, at its upper end, the overcrowded standard AM broadcast band.

Radio waves in this region of the spectrum reflect from the various layers of the ionosphere. Knowledge of the behavior of the layers, both periodic and in response to solar and nuclear events, is essential to prediction, as well as to increased knowledge of the process of wave reflection. Substantial progress has been made in several areas. Efficient methods for calculating the field of ELF, Very Low Frequency (VLF), or Low Frequency (LF) signals in the earth-ionosphere waveguide have been developed, which enable the complicated reflection processes in the ionosphere to be included in the calculations without any loss of accuracy. Calculations have also been made of the propagation of longwave signals during an ionospheric disturbance caused by a nuclear explosion or a solar proton precipitation event. Other analyses have been made which predict the change in shape of an electromagnetic pulse, such as that emitted during a nuclear explosion, as it propagates over great distances. These calculations are in close accord with observations of such signals.

Studies of the characteristic fading of VLF signals observed on long paths have confirmed that this phenomenon results mainly from varying degrees of interference of several propagation modes in the nighttime portion of the earth-ionosphere waveguide. In addition, it has been possible to determine the difference between the phase velocities and the attenuation rates of the first two nighttime waveguide modes. This work is particularly significant in arriving at improved models of the earth-ionosphere waveguide.

The use of realistic electron-density profiles for the lower ionosphere has led to some advanced analyses of waveguide modes which have proven useful in predicting the performance of VLF communication and navigation systems. Attention has also been given to calculating the transient characteristics of the waveguide—of importance to the problem of detecting nuclear explosions through the electromagnetic radiation which they emit.

Ionospheric Propagation Studies in the HF-VHF Range

The propagation of High Frequency (HF) and VHF radio waves is affected by the ionosphere sometimes favorably, at other times unfavorably. Included among the systems which use HF are the very extensive so-called "shortwave" telecommunications and broadcasting activities. On the other hand, although VHF systems can take advantage of the ionosphere in systems like ionospheric scatter communications, the ionosphere is mainly an occasional nuisance to FM and TV broadcasts at these frequencies.

The interaction of the HF radio wave with the irregular ionospheric medium is being given emphasis in present studies. Whereas the behavior of the long-term averages of the various ionospheric characteristics and propagation factors is fairly well known, the short-term behavior is quite variable and results in propagation effects which are difficult to predict. An understanding of the nature of the irregular ionosphere and its effects on high-frequency radio wave propagation will permit greater facility in predicting and compensating for these effects.

Experimental work has centered about the study of high-frequency ground backscatter, i.e., high-frequency radar echoes from the ground, propagated by way of the ionosphere. The technique is very sensitive to irregularities in the ionosphere, which focus and defocus incident energy. The use of this backscatter method shows considerable promise of making possible the measurement of ionospheric parameters at remote locations with a geographical resolution of a few tens of kilometers—through the use of a high resolution antenna system developed specifically for this purpose by ITSA.

Considerable effort has been expended during the reporting period on instrumentation for future experiments. Electronic circuitry has been constructed to provide two beams for the high resolution azimuth array and two for the elevation array at the Table Mountain field site, near Boulder. Electronically programed frequency synthesizers have been incorporated at both the transmitter and receiver sites and will permit multi-frequency observations on a short-time scale.

Experimental studies during the reporting period included the determination of the magnitudes of ionospheric focusing effects in both backscattered and forward propagated signals. Figures for effective ground scatter coefficients were also derived from the data obtained, which resulted in values higher than those previously reported.

In the area of theoretical studies, rays have been traced through model irregular ionsopheres to obtain insight into the mechanisms of ray interaction with these irregularities. Results indicate that modest changes in ionization density will provide focusing effects similar to those observed experimentally. These studies use a three-dimensional ray tracing computer program developed at ITSA, which has been documented and distributed to interested scientists as an aid in many aspects of the study of propagation. Another theoretical study has been concerned with the effects of irregular terrain in the vicinity of HF antennas on the propagation of radio waves, especially at low takeoff angles.

Analysis of the horizontal wave lengths of atmospheric disturbances in the stratosphere suggest that they may be the cause of some large traveling disturbances in the ionosphere. An understanding of the origin and nature of these disturbances is necessary to predict their occurrence and effect on telecommunications.

Research in Tropospheric Physics

The refractive index of the atmosphere is varied by turbulence as well as other factors, thus affecting radio propagation, particularly at frequencies greater than 10^8 Hz. Of particular interest is the effect on the transit time of signals over line-of-sight paths. Many types of telecommunications systems transmit their intelligence by varying the phase of the transmitted signal. Still other systems, used in radio navigation for missiles, rockets, satellites, and space probes, depend for their operation on the measurement of the time delays of signals transmitted from the target to two or more ground stations. In either case, random variations in propagation time will result from any heterogeneity in the refractive index of the troposphere. In many cases, the resulting phase variation limits the accuracy of the overall system. For this reason, it is important to first study the statistical properties of this "noise" and then to devise methods of circumventing or minimizing its effect. The ITSA program includes studies of the statistics of transit time variation under various atmospheric conditions at different geographical locations and in various parts of the spectrum from the microwave through the optical range.

In the field of optical propagation, a prototype two-color distance-measuring instrument has been developed. Laboratory tests have already demonstrated a potential precision significantly surpassing that of present commercial instruments. This new equipment will contribute to both the geodetic and the earthquake research missions of ESSA.

In a related project, a servo-controlled laser mount has been used for continuous observation of a laser beam traveling several kilometers through the atmosphere. The mount removes the problem of beam wander which previously precluded systematic observations. These laser observations, together with high-speed measurements of temperature fluctuations, provide useful engineering data and permit checks of optical propagation theory.

Research in Radio Meteorology.

Radio meteorology is the study of the effects of the atmosphere on radio wave propagation, and the use of these effects as a means of measuring atmospheric variables. Study has been in two general areas: radio climatology, and meteorological physics.

Radio Climatology. Radio climatology has as its objective the description of the radio refractive index structure of the atmosphere on a worldwide basis and its application to the expected performance of radio systems. Efforts are being made to predict radio propagation conditions from synoptic weather forecasts. These investigations include analysis of the effects of such phenomena as inversion layers, fronts, and subsidence, and the development of appropriate atmospheric models. Methods are being developed to apply climatological and synoptic data to the solution of particular problems—for example, position errors in radio tracking systems.

Meteorological Physics. Meteorological physics involves a detailed examination of the propagation medium. This research is both theoretical and experimental and investigates the behavior of those parameters which affect the refraction, reflection, absorption, and scattering of radio signals. Full use is being made of research results in other areas of study of the lower atmosphere. The objective of this research is the isolation and study of atmospheric properties that produce particular effects on radio propagation, with the aim of eventual development of non-empirical means for prediction. Atmospheric studies include: Spectral characteristics of the radio refractive index and its relationship to atmospheric stability, the nature of water vapor fluctuations, the effects of air mass movements, convective activity, hydrometeors, jet stream and tropopause phenomena, wind shear, subsidence, and the origin and characteristics of thin upper air layers. An experimental program of field measurements is in progress concerned with refractive index turbulence, water vapor evaporation studies by electromagnetic means, radar returns from the clear atmosphere, airborne and ground-based refractometry and humidity measurements, correlation studies of within-line-of-sight fading of radio signals along with atmospheric fluctuations, and simultaneous air-to-air, air-to-ground, and ground-to-ground radio meteorological studies.

Evaporation from lakes and rivers is of increasing importance to water conservationists and in studies of the hydrologic cycle. Of particular interest was a joint study conducted at Lake Hefner, Near Oklahoma City with the Bureau of Reclamation in connection with the Bureau's investigation of the utility of thin films to retard evaporation. It was desirable to find a means of measuring, not merely the average evaporation over a period of weeks, but the minute-to-minute evaporation rate as a function of environmental variables. Using its knowledge of relationship between water vapor content and atmospheric refractive index, TTL was able to make

At Lake Hefner, Okla., water evaporation rates are studied by correlating the effect of humidity on the variation of a radio signal being received by the radio refractometer.

the desired measurements, using a radio refractometer and a sonic anemometer developed especially for the purpose. This anemometer also shows promise for turbulence studies. Results of this program will also be useful in studies of sea-air interaction.

Studies of the atmospheric structure and properties as related to transmission and emission of radiant energy at infrared frequencies have been made. These provide theoretical foundation and experimental data to aid in the design and development of remote sensing methods and telecommunication techniques.

PREDICTING THE SPACE ENVIRONMENT

The sun plays a primary role in influencing the dynamics of the total environment, and hence the study of real-time solar-terrestrial relationships is critical to the search for improved means of prediction and warning. At the same time, ESSA has a direct and immediate interest in solar behavior because the sun is the source of highly energetic particles and other space disturbances which have a profound effect on both communications and safety in the earth's near-space environment.

Space Disturbance Forecasting

ITSA's Space Disturbance Laboratory plays a leading national role in the study of such solar-induced space disturbances in support of its responsibilities in the field of space environment forecasting. Research and development programs are concerned with improvement of techniques, methods of predicting solar events, the study of solar interactions with the earth's magnetic field, measuring the response of the ionosphere to solar events, and the application of the knowledge gained, both to forecasting and to detection of high-altitude nuclear events. The Space Disturbances Laboratory conducts basic research into the nature of disturbances in the space environment of the earth, particularly those associated with solar activity. Studies are undertaken in the following fields: Solar activity, solar-terrestrial relations, the interaction of the solar wind and the magnetosphere, magnetic storm theory, the interaction of solar protons and the upper atmosphere, trapped particle phenomena and auroral disturbances, ionospheric storms, and infrasonic phenomena.

Instruments, Systems, and Techniques Development

As in the case of telecommunications, instrument and systems development in this area is largely carried out as an integral part of research programs. One major activity which has broad applications is the development of numerical means of preparing short-term forecasts of solar activity, based upon the methods developed for weather forecasting by NMC. The techniques under development use sophisticated statistical procedures to select optimum predictors and to test their statistical significance. New programs have been prepared for verification of forecast results against an independent data sample, as have new statistical procedures for preparing forcasts when significant percentages of the input data are missing.

Prediction of Solar Events

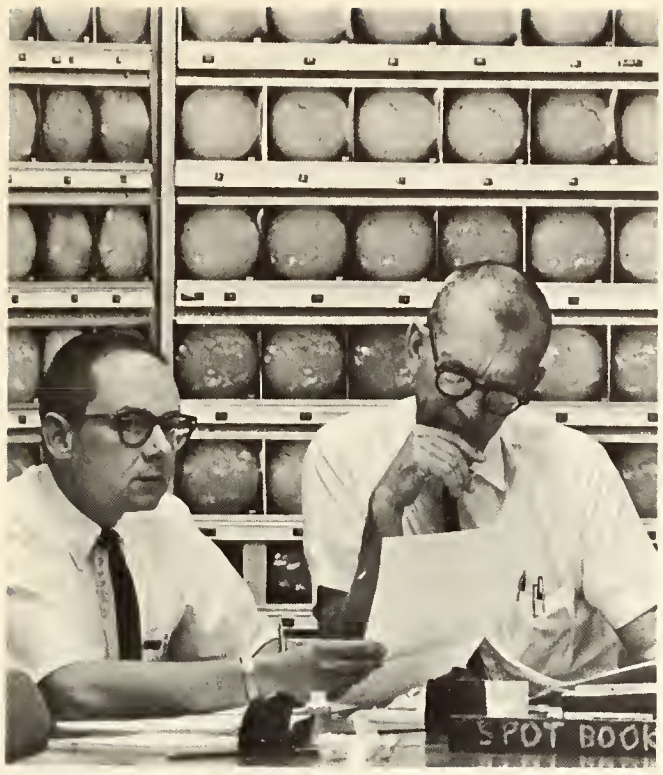
The origin of the most significant disturbances in local space is, of course, the sun. Thus, major emphasis is placed on study of the emission and propagation of solar radiation, its effects on the earth and its environment, and its relation to various forms of solar activity, with the aim of improving the accuracy of disturbance predictions. It was found that solar flares which produce large fluxes of energetic protons, and hence are potentially dangerous, show a pronounced tendency to recur along certain solar meridians. It is believed that this apparent tendency to cluster may prove to be a useful predictor of solar proton events.

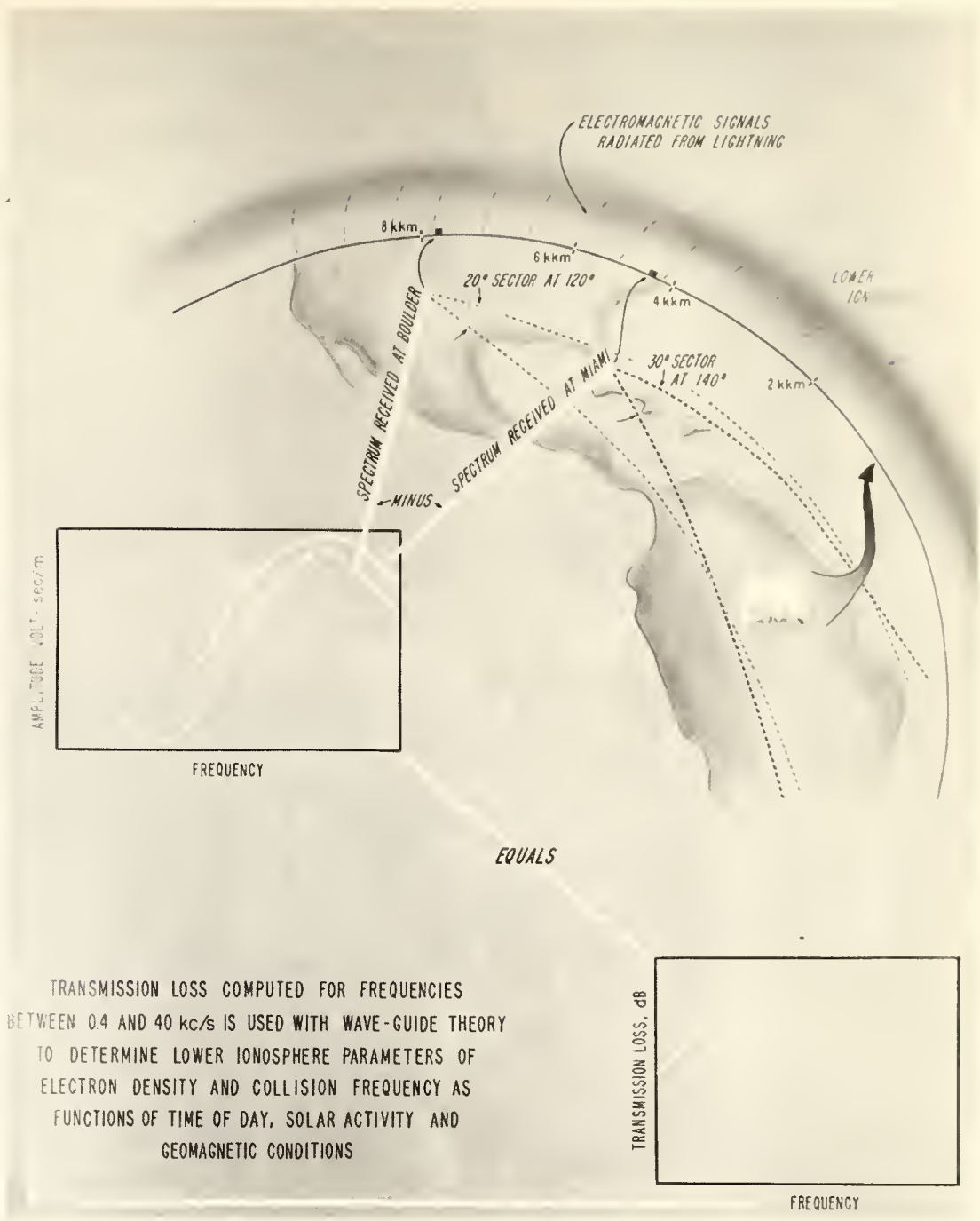
With the aim of securing more uniform and more significant input data, work has continued on the grouping and standardizing of flare reports and solar radioburst data. Frequent observation of sunspots and other solar surface features are now made at Boulder so that forecasters have the benefit of rapid information and of the "feel" of a developing active region. A new morphological classification of sunspot groups has been proposed for forecasting.

Some practical contributions to solar disturbance forecasting have also been made. Various optical and radio observations of the sun and ionosphere that give early warning or detection of solar protons have been surveyed and evaluated as predictors. With the help of a time-shared computer, daily and weekly estimates of the future level of geomagnetic activity, based on current and past indices of activity, have been made. Also, a computer program for editing flare reports has been developed that will be useful in real-time forecasting as well as in early dissemination of flare data.

Solar flare events are often followed, after an interval of some tens of seconds, by radio bursts at meter wavelengths. Thus, flare-induced disturbances far out in the solar corona can be conveniently studied by radio methods, and the subsequent evaluation of these radio bursts may offer clues to the direction of travel of potentially dangerous solar particle streams in the interplanetary medium.

In cooperation with the University of Colorado's Department of Astro-Geophysics, a sweep frequency radio interferometer covering the range 7–40 MHz is being used to obtain information on meter wavelength solar bursts. Data are telemetered to the Space Disturbance Forecast Center in real-time. Studies are currently in progress on the problem of improving both the frequency coverage and the spatial resolution. Under design is a wide-band interferometer system for defining the position of solar bursts to within a few minutes of arc. This will aid in identifying those bursts which are most likely to cause disturbances in the vicinity of the earth.





Every 6 hours, scientists of the Space Disturbances Forecast Center of the Space Disturbances Laboratory at Boulder, Colo., issue forecasts of solar weather to government agencies, universities, and private industries. These forecasts are helpful in maintaining the efficiency of telecommunications and satellite and other electronics operations which solar emissions can disrupt. (Right) Electromagnetic radiation produced by lightning flashes in South America propagate in the Earth-ionosphere waveguide past the observing sites at Miami and Boulder. The differences in the shapes of the spectra observed at these two sites is used to deduce the electron deviation in the magnetosphere.

Solar Interactions With the Earth's Magnetic Field

The earth's magnetic field forms a "shell" around the earth which can be penetrated by very energetic particles from outside or distorted by lower energy particles—in either case, potentially resulting in significant disturbance to the space inside the field called the *magnetosphere*. The program in this area of research deals with the interaction of the low-energy *solar wind*, or flux of plasma ejected from the sun into space, with the planetary magnetic fields. Both quiet and active solar conditions, together with anomalous events, such as flare-ejected plasma clouds and their associated blast waves, are considered. Thus, the normal or quiet state of the earth's magnetospheric "bumper," together with streaming of low-energy protons and electrons through the standing shock wave, is examined first, followed by analyses of transient shock associated with the blast wave interaction with the earth's shock. The impulsive dynamic pressure pulse caused by shock impingement on the magnetospheric boundary may be responsible for the sudden geomagnetic storms observed at middle and low latitudes.

Much of this analysis is based upon data obtained from earlier spacecraft penetrations of the magnetosphere of the earth and other planets, but another approach to the study of the magnetosphere and its interactions is through the phenomena known as *whistlers* and *VLF emissions*. These are natural phenomena, whistlers being generated by lightning flashes, and VLF emissions by the interaction of incoming energetic particles with electromagnetic radiation in the magnetosphere. Since both these phenomena develop at VLF frequencies, they are subject to the wave-guide type of propagation along the earth's magnetic field lines which was described in the previous section. Theoretical analyses of these events are used to estimate the electron density in the magnetosphere, including the variations associated with space disturbances.

General view of the observatory at the Space Disturbances Monitoring Station near Anchorage, Alaska. (Below) Strip charts are used to record changes in the space environment of the earth as detected by ground-based instruments.

Ionospheric Interactions

Having interacted with the earth's magnetosphere, solar disturbances eventually produce corresponding disturbances in the ionosphere, which are detected and measured by a variety of techniques. The response of the ionosphere to various kinds of disturbing influences can only be understood if there is sufficient knowledge about the basic physical processes which are pertinent to the D, E, and F regions of the ionosphere. A theoretical program based on experimental results seeks to interpret these results in the light of processes which are now thought to occur. A systematic search for new processes hitherto overlooked is being conducted with special emphasis on those involving excited states of the atmospheric atoms and molecules. An experimental program is being developed to study optical emissions from such excited atoms and molecules and will encompass both ground-based and rocket-borne observations. Instrumentation for the program now beginning will include a scanning Fabry-Perot interferometer, a rocket-borne infrared radiometer, and a two-meter Ebert spectrometer.

ITSA scientists are using an advanced radio technique for the detection and study of transient changes in the ionosphere associated with solar or atmospheric disturbances. Time variations of the ionosphere are continuously monitored by recording the deviations in the

received frequency of HF radio waves which are transmitted from frequency-stable ground stations and are reflected from the ionosphere. This technique provides a sensitive means for detecting the ionospheric effects of solar flares and indirectly improving knowledge of solar flare radiations and their ionizing effects in the E and F_1 regions of the ionosphere. It also provides observations of transient geophysical phenomena originating in or near the earth's atmosphere, such as acoustic-gravity waves, effects of earthquakes, and effects of magnetic storms.

Solar flare ionospheric effects provides one type of data used by ESSA's Space Disturbance Forecast Center. Data from this program are also important in providing background information to ITSA's High Altitude Nuclear Detection (HANDS) program to help differentiate between the ionospheric effects of solar flares and those due to high altitude nuclear explosions.

The observations of transient geophysical phenomena provide important data on the coupling of energy between the lower and upper atmosphere of the earth, which is essential in understanding the behavior of the total environment as a coupled geophysical system. A study is underway of the association between acoustic disturbances at ground level and certain distinctive oscillations of the F_2 region of the ionosphere overhead.

Theoretical studies and experimental measurements on the generation and propagation of infrasonic waves through the atmosphere are conducted and interactions between sound waves and other geophysical phenomena are being studied for use as a basis in deducing certain fundamental physical properties of the atmosphere, of the earth, and of the seas. Two new infrasonics stations at Huancayo, Peru, and near La Paz, Bolivia were completed during FY 67. Each station is able to record the waveforms of sound waves in the range of oscillation periods 1 second–1,000 seconds, and to determine from these the strength, azimuth of propagation, and horizontal trace velocity.

Hazard Studies

The primary environmental hazard in near-space both for man and telecommunications is the occasional burst of high energy particles from the sun. Thus, there is considerable emphasis in ESSA on research into the energetic particle environment of the earth, the mechanisms that govern this environment and its influence on man, and the associated deterioration of radio propagation conditions at high latitudes. A second type of event of importance is the more frequent precipitation of high energy electrons into the ionosphere near the earth's magnetic poles. Called polar cap absorption (PCA)

View of the field site of the High Altitude Nuclear Detection Studies program located on Table Mountain north of Boulder, Colo. The radome contains a 3-cm. solar radiometer.

events, the precipitations can have a major disruptive effect on radio communications.

The principal observational tool presently being used is the *riometer* (a galactic noise radio receiver), which provides direct ground-based measurements of particle precipitation into the upper atmosphere by monitoring the strength of the galactic noise signal transmitted through the ionosphere, which is a function of the ionospheric electron density. Virtually all measurements are carried out at high geomagnetic latitudes (greater than about 60°), since most energetic particle effects are confined to these regions. The present program has grown out of an earlier study of the similarity of effects occuring at conjugate points, i.e., at points in the two hemispheres linked by lines of force of the geomagnetic field.

The conjugate aspects of electron precipitation in the auroral zones are currently being studied in detail, using multiple antenna systems at Byrd, Antarctica, and Great Whale River, Quebec—two conjugate sites located near the heart of the auroral zones, where energetic electron bombardment of the atmosphere is most frequent. Each of these systems, which were installed in December 1965 and January 1966, consists of five separate antennas, beamed respectively vertically and at 45° to the vertical in the geomagnetic north, south, east, and west directions, each antenna being connected to a separate riometer. The objective is to study the spatial variability of electron precipitation at both ends of a field line and to look for evidence of deformation of the geomagnetic field lines as revealed by changes in conjugacy during precipitation events. To aid in analysis of the data, both analog and digital paper tape outputs are employed at both locations.

Satellite work performed during the reporting period has included the analysis of data received from a radio beacon experiment on board the Orbiting Geophysical Observatories, OGO–1, OGO–3, and preliminary planning for a solar proton monitoring subsystem to be placed on board forthcoming operational weather satellites in the improved TOS series which will become available in 1969. This project is being carried out in cooperation with NASA's Goddard Space Flight Center, the Applied Physics Laboratory of Johns Hopkins University, and NESC.

High-Altitude Nuclear Detection Studies

A program for continuously monitoring the ionosphere has been established to identify and record ionospheric disturbances and to distinguish between those of natural origin and those caused by high-altitude nuclear explosions. Site of the operation is the ITSA Table Mountain Observatory near Boulder, Colo. Data from some 50 sensor channels involving measurements of radio frequency, magnetism, optical parameters, and 3 cm. incoming radiation are processed by computer in real-time and used to automatically generate an alarm which is telemetered to the Space Disturbance Forecast Center.

The System has also proved to be effective in detecting solar flares and a flare alarm system was established during the present reporting period. In addition, a system for automatically calibrating the radio frequency sensors was developed and placed in operation. The latter will be important in ensuring reliable operation of equipment at unattended sites.

6 ENGINEERING ACTIVITIES AND SERVICES

ESSA performs a third service which is neither description nor prediction and yet embodies elements of both these activities to produce direct action in support of its missions or in support of the programs of other agencies. Although there is a high order of scientific content in many of these activities, they are referred to here as engineering activities because they are directly relevant to practical problems. Fields included are: Engineering services in geomagnetism, seismology, the ocean environment, climatology, hydrology, and telecommunications; those programs dealing with the engineering properties of the atmosphere; and modification and control of the environment.

GEOMAGNETISM

One of ESSA's most important missions is to measure and chart the geomagnetic field for navigational and other purposes. The earth's magnetic field was one of the earliest environmental factors used by man. It is generally agreed that the magnetic compass came into use by European navigators in about the 12th century A.D., although it may have been used even earlier elsewhere. Today's navigators require far more accurate knowledge of the precise value and direction of the earth's magnetic field than did their 12th century predecessors.

Direct engineering activities in geomagnetism include the maintenance and provision of calibration standards, and the international calibration of magnetometers by simulation of the field intensity and direction at any point on the globe. These activities are performed by the Office of Seismology and Geomagnetism of the Coast and Geodetic Survey (C&GS) and its Fredericksburg Geomagnetic Center at Corbin, Va.

ENGINEERING SEISMOLOGY

Information available presently or in the near future will permit designers to anticipate earthquake forces in planning structures for potential earthquake areas. ESSA, together with the National Bureau of Standards (NBS), conducts a program in this area. This program involves continuing studies in strong motion effects, soil mechanics, seismicity, structural and utility design techniques, and economic cost and benefit analyses.

Research and Development Organization and Facilities

ESSA's program of research and development in support of services in engineering seismology is performed by the Office of Seismology and Geomagnetism of C&GS at a number of field locations and at its headquarters in Rockville, Md. The Office is supported by the instrument development and test facilities of its Albuquerque Seismological Center.

Instruments and Systems

Many of the same instruments and systems developed and acquired for other programs find application in the engineering seismology effort. The primary tool here is the strong-motion seismograph, which is designed to record the large motions in the vicinity of earthquakes, rather than the seismic waves from distant events. The Portable Seismograph System was specifically designed for engineering studies and can be installed by one individual, who can easily operate and service four such systems located over a wide area due to the length of time possible between record changes. Such instruments would be taken to the site of a recent earthquake to record aftershocks.

C&GS also operates a network of fixed strong-motion stations in the western United States, Alaska, and South America. These seismographs remain inoperative until triggered by an earthquake, which causes them to run for only a few seconds unless the recycling device is again activated by earthquake motions. These instruments are essential for studying the nature and magnitude of destructive earthquake movement. Data collected by them provide the basis for design criteria in earthquake-prone areas.

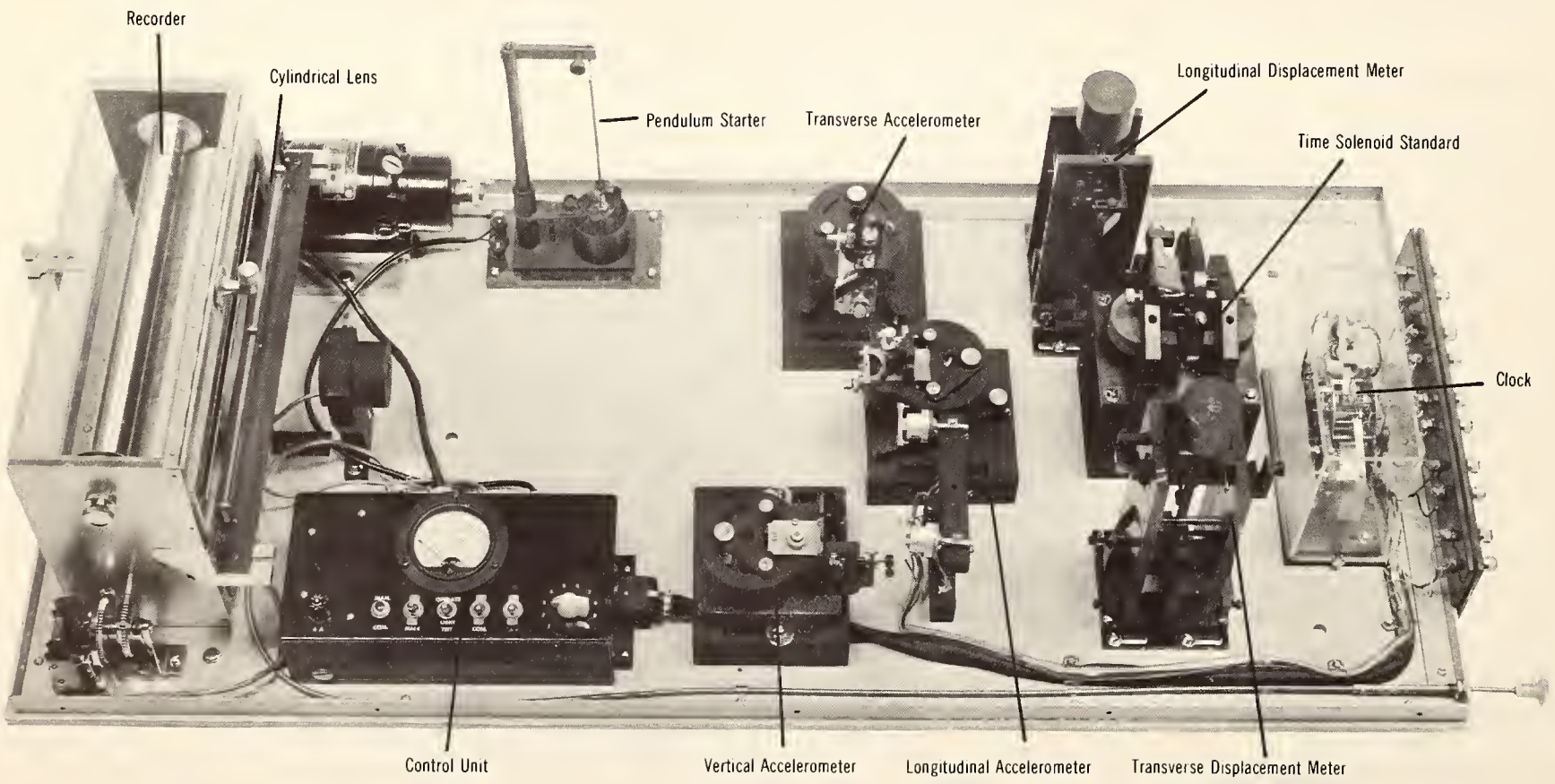
The strong-motion program of C&GS includes the operation and maintenance of several hundred strong-motion seismographs and seismoscopes in North and South America. These instruments are installed in earthquake-prone areas having different soil conditions and in manmade structures of varying design and number of floors. Preliminary analysis of amplitude and period and copies of the original seismograms are made available to educational and research institutions and State and Federal agencies for theoretical studies and for development of safety codes and regulations.

Specifications have been completed and procurement of major items has been instituted for a data processing system which will provide magnetic tape handling facilities necessary to make hard copies of seismic events, determine and catalog event times and time corrections, compile and store master analog tapes of seismic events, rehabilitate field tapes, and transform analog data to digital form for computer entry.

Aftershock Studies and Field Investigations of Destructive Earthquakes

Seismicity and aftershock studies offer the direct approach to the problem of earthquake prediction. Seven damaging earthquakes, the Prince William Sound, Alaska, earthquake of March 28, 1964; the Rat Island earthquake of February 4, 1967; the Puget Sound, Wash., earthquake of April 29, 1965; the Mexico earthquake of August 23, 1965; the Dulce, N. Mex., earthquake of January 23, 1966; the Parkfield, Calif., earthquake of June 28, 1966; and the Chilean earthquake of December 28, 1966, have been investigated. The area of each of these events was instrumented with temporary seismographs to record aftershocks. Field studies of structural damage and an assessment of the intensity distribution in the macro-seismic area were conducted. The studies of the Puget Sound, Rat Island, and Parkfield earthquakes have been completed and reported. Reports on the remaining four earthquakes are now in preparation.

The most extensive of these studies are those of the Prince William Sound, Alaska, earthquake, presented in two volumes. Volume I, which contains the earthquake history of Alaska as well as details of the instrumentation of the aftershock area has been published. Volume II contains extensive basic investigations into the seismological effects of the main shock and its aftershock sequence. It appears in two sections corresponding to natural divisions of the studies presented. Volume II, Part A, *Engineering Seismology*, contains research on those aspects of applied seismology concerned with the effects of the earthquake on various types of engineering materials and construction, and the application of the knowledge thus gained to the design of earthquake-resistant buildings; included also are the relationships of soil mechanics as a factor in foundation support or failure—and hence, also, the influence of the geological substructure upon earthquake damage.



The Strong Motion Seismograph. Seismic events exceeding a predetermined threshold are recorded automatically by this device.

Part A is prepared essentially for the use of design and structural engineers or others studying the effects of the earthquake and its accompanying landslides upon various types of building construction found in the Alaska area—including wood frame, steel frame, masonry, and prestressed and reinforced concrete. The practical aspects of engineering seismology discussed involve detailed appraisals of earthquake damage suffered by various types of structures subjected to seismic waves of differing frequencies; the objective analysis of the relative influence of the earthquake and aftershocks upon similar types of building design and construction situated upon different geological substrata; and the evaluation of free-period vibratory motions in building structures. A consideration of the possible use of microseisms as an indicator of resonance phenomena affecting earthquake structural damage is also included.

This cooperative publication between C&GS and other organizations concerned with the design and fabrication of earthquake-resistant structures is a major contribution to the technical literature of this field. The application of such structural design knowledge and practice to seismic building codes is of especially vital significance both to the protection of lives and to the economic welfare of earthquake-prone areas.

Volume II, Part B, *Seismology*, covering what might be termed "pure" seismology in connection with the Prince William Sound earthquake, was prepared by seismologists of C&GS Geophysics Research Group, the Seismology Division, and the Seismological Field Survey Office of C&GS in San Francisco, Calif. These studies involve extensive statistical evaluations of the observational data obtained during and after the principal earthquake, as well as analytical and theoretical interpretations of these data. A discussion of the seismic sea wave or tsunami generated by this earthquake, and of the function of the tsunami warning system, is also contained in Part B. Such studies of seismic sea waves may be subdivided into (a) the nature of the source; (b) the propagation characteristics of the seismic wave through the ocean; and (c) the effects of runup as seismic sea waves encounter shoaling water, beaches, and landmasses. In addition, cooperative arrangements were made with seismologists of the Tokyo Institute of Geophysics and the Lamont Geological Observatory of Columbia University to include in Part B of this report special research papers describing the microseisms produced by the Prince William Sound earthquake and its aftershocks.

Volume II, Part C, *Marine Geology*, is included under the same cover with Part B because of the causal action of differential movements along faults in the ocean floor in triggering earthquake aftershocks, and contains studies of fault scarps created on the sea bottom and modification of the submarine terrain as a result of the earthquake. Part A of Volume II has been published, and Parts B and C are in process.

Soil Mechanics

In the field of soil mechanics, C&GS has, in the past, assigned ground amplification factors to various soil formations so that the strong-motion seismographs would not go off scale when recording strong earthquakes. Because these values are not sufficiently precise for the design of earthquake-resistant structures, the Survey has recently developed the "engineering type" seismographs referred to earlier in this report to obtain additional data on ground amplification. These special seismographs are accurately calibrated and have been operated in earthquake areas of the West Coast.

In addition, a project is now underway to investigate the effects of local geology and soil conditions on seismic waves. High-gain seismographs of the type normally used for teleseismic recording are being employed to obtain the necessary data. During one phase of the experiment, these instruments will be placed at the sites of six strong-motion stations in the El Centro and San Francisco, Calif., areas where good strong-motion recordings were obtained from the 1940 and 1957 earthquakes. The results will allow comparisons to be made for the first time between the ground motion due to small and relatively large earthquakes. The results of this study should assist in resolving the important question of the degree to which it is possible to extrapolate from small to large ground motions. Additional information will be gained on such effects as nonlinearities and increased energy dissipation, which may be greatly altered with size of the ground motion.

The effects of geology and soil conditions are being studied in a similar manner in the Bakersfield, Calif., area under a cooperative agreement with the California Department of Water Resources.

Seismicity

The compilation of seismic zoning maps is the starting point for antiseismic design of structures and for the formulation of building codes which provide a reasonable balance between economics and safety. The basic questions in this study center on the prediction of earthquake occurrences, the frequency of occurrence, and their macroseismic consequences. ESSA is seeking answers to these questions through statistical studies of earthquake occurrence, consideration of recent tectonics, studies of the relationship between earthquake occurrence and large through-going faults, and studies of the amplification of seismic waves by various geologic media. To facilitate this, a complete compilation of historical accounts of earthquake occurrence in the United States has been listed on a punched-card format for computer analysis of statistical patterns. The relative recurrence rate and its variation over the United States is being determined. These results are presented in terms of equivalent numbers of earthquakes per unit area for a standard energy level.

In addition, continuation cards for each event contain information over the entire macroseismic area of an event

where damage occurred, making it possible to investigate not only local, but regional influences on the macroseismic pattern of damaging earthquakes. Maximum intensity and strain release maps are now in preparation.

Design Techniques

ESSA conducts a program to furnish data for development of building codes for earthquake-resistant designs. C&GS reports of earthquake damage and engineering surveys of damaged buildings are analyzed as a basis for recommendations. Acceptance of such codes by State and local governments in areas of high earthquake probability would be voluntary. Such acceptance would provide affected areas with a comprehensive, effective, rational code.

Economic Cost and Benefit Analysis

With the assistance of the National Bureau of Standards, ESSA has carried out a study of the benefits expected to result from the expansion of programs in engineering seismology. The study seeks to determine whether greater use of data from such programs would have a significant effect on reducing casualties and damage to structures. While information is available concerning the recording of seismic events and their interpretation, there is little known of the utility of such information to architects, engineers, and the public.

Within funding and time limitations, it was possible to obtain data from school buildings in several California areas and in King County (Seattle), Wash. Comparisons were made between structures built without earthquake-resistant design and those constructed with design approval based on C&GS seismological data (which has been supplied continuously for 30 years). Under roughly similar earthquake conditions, the nonresistant buildings showed average damage of 67 percent while the resistant ones showed average damage of less than 1 percent.

Engineering Applications

Another current program is a feasibility study to determine whether an interoceanic canal can be dug with nuclear explosives in Central America. Earth motions produced by large-scale explosions are limiting factors for seismic safety, requiring prediction capabilities to minimize damages by controlling the charge sizes.

The use of charges placed in a row for excavating trenches is in the experimental stage with specific application to digging the interoceanic canal. A recent test project, in which C&GS participated, was the Dugout Test, which consisted of the explosion of five 20-ton charges of conventional explosives placed in five holes separated by 13.17 meters at depths of 17–28 meters.

For over 40 years, seismology has been the best technique for locating mineral deposits on land. This technique is currently being applied to the ocean bottom by C&GS ships. This is of particular utility to the location of offshore petroleum deposits.

GEODETIC ENGINEERING SERVICES

Geodetic engineering services have been provided for over a century by C&GS, in the form of special surveys to determine property lines, boundaries between States, precise elevations of structures, etc. In addition, special maps and charts are made available to surveyors to provide control for their work. Perhaps the most commonly known engineering tools furnished by the Survey are the bench marks—metal markers placed permanently in the ground at thousands of locations in the United States and its possessions—to provide precise geographical coordinates for use by surveyors and engineers.

Sampling beach sand in the swash zone at Virginia Beach, Va. Such studies, conducted by the Land and Sea Interaction Laboratory, are used in the development of equations by which beach response to oceanic forces can be predicted.

OCEAN ENGINEERING

As in the fields of geomagnetism and geodesy, ESSA's contributions to the practical use of the ocean environment are primarily in the form of description and prediction.

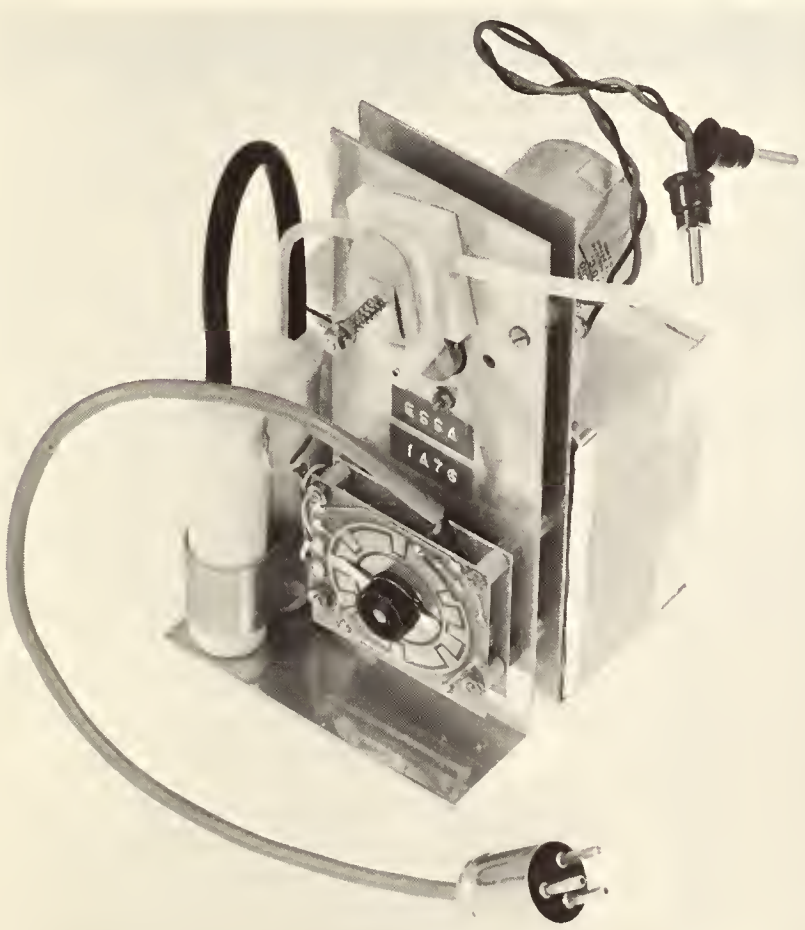
However, during this reporting period, the Land and Sea Interaction Laboratory of the Institute for Oceanography sucessfully completed a project to determine the bearing strength of estuarine sediments in the lower Chesapeake Bay. Results of the project indicated that the actual bearing strength for plate loads was substantially greater than would have been estimated on the basis of conventional triaxial tests. This suggested that new standard testing procedures be developed, calibrated against *in situ* measurements with the type of equipment developed for this project. This type of information is vital to designers of bridges and other structures in estuarine waters, and these results should be of general value in other locations.

The Sea Air Interaction Laboratory of the same Institute has initiated a long-term study of typical wave formation under various meteorological conditions on the Great Lakes. This program should result in information which will be useful in the development of designs for future Great Lakes ships, and should also be of value in utilizing the present fleet.

CLIMATOLOGICAL AND HYDROLOGICAL ENGINEERING SERVICES

Agriculture, defense, industry, construction, transportation, conservation, recreation, health, and safety programs all depend in varying degrees on the products of ESSA's climatology program. The Environmental Data Service (EDS) performs analysis and consultation on specific problems where required. For example, engineers require a simple method for forecasting air-conditioning loads, so that they can estimate the energy consumption to be expected from air-conditioning systems under normal and unusual operating conditions. The results of a special EDS study indicated that data from dry-bulb temperature degree days above 65° F were as suitable for this purpose as were data including the humidity factor, thus simplifying the measurements which must be made. These results, together with an extension of methods for obtaining degree days above any base, facilitates the use of the dry-bulb method. It is now used for 30-day forecasts of air-conditioning system energy requirements. Other programs include studies of snow load on structures and the conversion of ground snow depths to roof loads, analysis of prevailing winds at proposed airport locations, and analysis of average and probable maximum wind loads on structures.

Similarly, the Weather Bureau's Office of Hydrology performs special analyses of average and probable maximum precipitation and runoff for the designers of dams and other water management structures.



The Komhyr carbon-iodine ozonesonde, a balloon-borne device which measures the concentration of ozone in the atmosphere.

ATMOSPHERIC ENGINEERING RESEARCH

In addition to providing climatological services, ESSA has a major interest in developing new knowledge of the engineering properties of the atmosphere.

Clear Air Turbulence

An important program in this area is the study of atmospheric turbulence as it affects aircraft flight, particularly the type encountered without warning in clear air far from any storm. This phenomenon, labeled CAT (Clear Air Turbulence) by pilots, is becoming a major hazard to flight with increasing aircraft speeds and altitudes. The Department of Defense estimated a loss of $30,000,000 from 1963 to 1965 due to CAT, with an additional estimated loss in civil aviation of $18,000,000 during the same time period, not to mention the injuries and loss of life sustained. It is anticipated that CAT will become an even greater problem with the advent of supersonic transport aircraft.

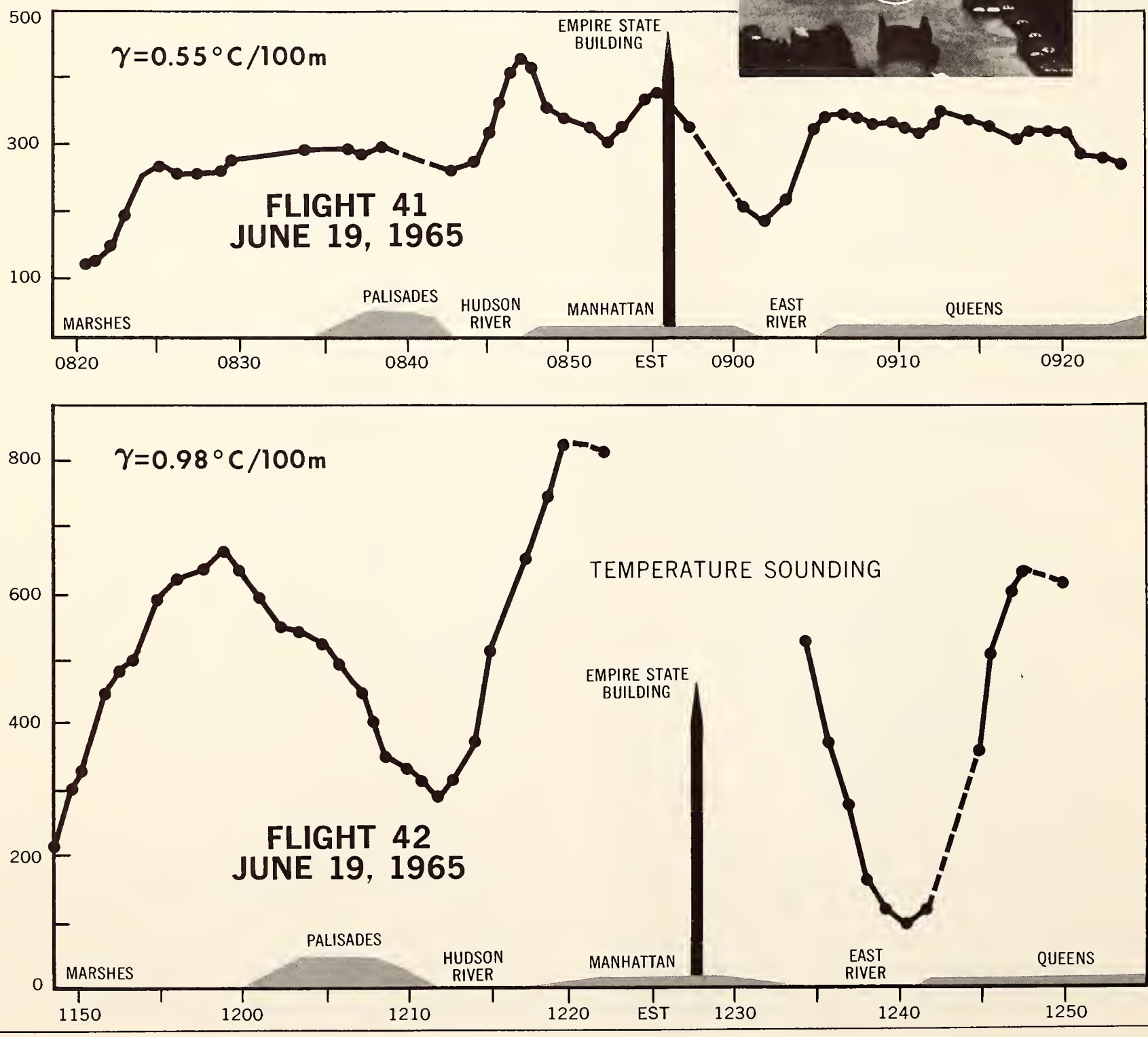
ESSA is concerned with predicting the occurrence of CAT and issuing warnings to pilots flying in areas of probable CAT. In support of this service mission, the Institute for Atmospheric Sciences (IAS) has conducted a study of variation in rawinsonde ascension rates as related to the occurrence of CAT. Preliminary results suggest that a statistically significant relationship may exist between the two phenomena.

To provide data for aircraft designers, and as an aid in the establishment of flight procedures in Clear Air Turbulence, ESSA is studying the turbulent structure of the atmosphere at the altitudes where supersonic transports will fly. Determination of the aerodynamic response of an aircraft in all phases of its flight, the consequent structural response of the airframe, the comfort and safety of passengers, and the performance of engines must all be related to a detailed analysis of the characteristics of the types of CAT which may be encountered. Detailed analyses of temperature and wind fields associated with turbulent zones form the basis of the program.

Atmospheric Pollution

The large increases in population, industrialization, and the use of the internal combustion engine are intensifying the pollutants in the atmosphere. Contaminants introduced into the atmosphere may inadvertently produce adverse changes in weather and climate. Thus, ESSA has a two-fold interest in the relationship between meteorological vectors and pollution. Activities in this

Altitude profiles as a function of time for two balloon flights over New York City. Altitude variations indicate vertical air currents. Insert: A tetroon, a tetrahedral balloon which remains at a constant altitude unless displaced by vertical air currents.



area include theoretical studies of the mechanisms involved, experimental studies of atmospheric trajectories and the dispersal of radioactive contaminants, and the study of other meteorological factors relating to pollution. In most of these programs, ESSA performs a service function in support of other Federal agencies having primary responsibility for operations which fund research, development, and engineering programs directly.

Inadvertent Weather Modification

Research in the area of inadvertent weather modification has been concerned with the effect on the radiation budget of various parameters including gases (CO_2 and O_3), particulate matter (cirrus clouds), and surface reflection (albedo). Comparison flights between the ESSA-developed Komhyr carbon-iodine ozone-sonde, the Regener luminescent sonde, and the recast electrochemical sonde have established the reliability of the Komhyr sonde.

Theoretical Turbulence and Diffusion Studies

Problems under investigation include such areas as: Diffusion in the surface layer, height of rise of smoke under various conditions, the boundary layer over a city, and the relationship of boundary layer conditions to phenomena such as the sonic boom.

Trajectories and the Dispersal of Contaminants

The Air Resources Laboratory of the Institute for Atmospheric Sciences continued its study of the transport, dilution, and removal of atmospheric radioactivity during this reporting period. Comparisons of gaseous (carbon–14) and particulate (strontium–90) radioactive products were made to determine if small particulates act as true tracers in the stratosphere. Evidence is accumulating to confirm this hypothesis.

Although only a very few nuclear tests injected radioactivity into the atmosphere in 1965 and 1966, there remains a need for meteorological description of the disposition of such injections from both past and future events. The Laboratory provides assistance to the Federal Radiation Council in its predictions of strontium–90 and cesium–137 fallout from the nuclear debris still in the stratosphere from previous nuclear detonations. The Atomic Energy Commission requires knowledge of the consequences of radioactivity in the upper atmosphere resulting from the use of nuclear energy in space. The main effort of research conducted in the field of atmospheric radioactivity was directed at a better understanding of the stratosphere since it is in this region that the more massive test inputs have occurred and may occur, and where burnups of space vehicles are likely to place their radioactivity. Developments in this area include:

- A simple two-dimensional model of particle distribution.
- Identification by balloon-borne devices of persistent sub-synoptic planetary boundary layer structures and the determination of shearing stresses at or near 500 meters above the surface.
- A mountain-valley diffusion model.
- Preliminary demonstration of a "megalopolis" diffusion model.

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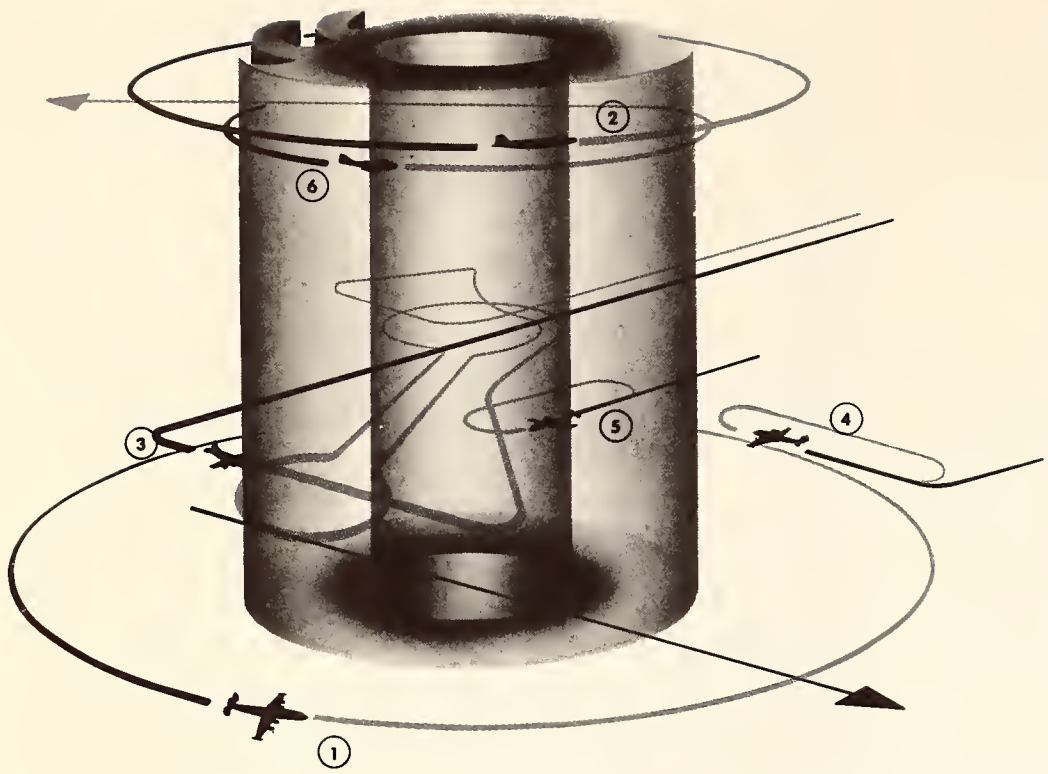
The Laboratory has also completed a draft of the second version of *Meteorology and Atomic Energy*. This revision incorporates the latest information and techniques on atmospheric diffusion. The original version, published by the Weather Bureau in 1955, is now out of print after having sold more than 10,000 copies and having been translated into several foreign languages, including Russian. The information in this compendium is used extensively in making safety analyses of various types of nuclear facilities and experiments in which there is a possibility of both routine and accidental emission of radioactive material.

Accurate measurements of three-dimensional air motion have been obtained in detail over distances of 50 miles or more by a new technique developed by ESSA personnel. The instrumentation involves radar tracking of a miniaturized radar beacon carried by a small constant volume ballon, which tends to stay at a constant altitude unless it encounters vertical currents. The technique is especially useful in measuring motions over inaccessible locations such as large open water areas and rugged mountain regions. One of the major efforts during the year was the analysis of "tetroon" trajectories flown over the New York City metropolitan area to determine possible causes of local weather phenomena. Definite effects of the city's structure upon air motion were observed.

The Meteorology of Air Pollution

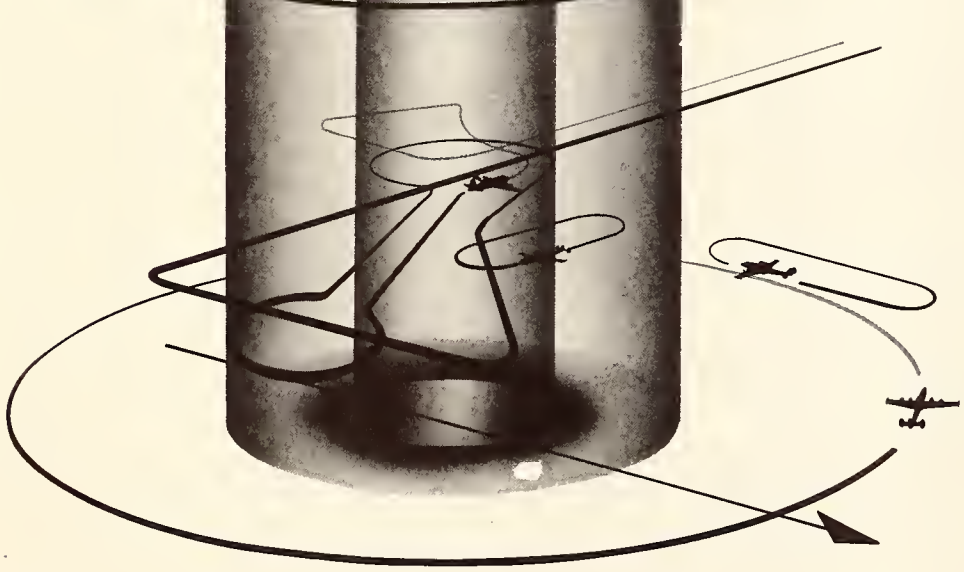
The Air Resources Field Research Office at the Robert A. Taft Sanitary Engineering Center of the U.S. Public Health Service in Cincinnati, Ohio, has the responsibility for conducting research in the meteorological aspects of urban air pollution. During the past year, the National Meteorological Center (NMC) at Suitland, Md., has provided the Cincinnati group with daily information on the depth of the atmospheric mixing layer and the mean wind speed in that layer at all upper air stations in the conterminous United States. These parameters, in turn, form the basis for an objective forecast model of atmospheric pollution potential. On July 1, 1966, NMC commenced preparation of air pollution potential forecasts by machine methods on a regular basis. After a year's trial period, the NMC forecasts showed sufficient development to supplant subjective estimates and are now issued as the official national forecast in the preparation of advisories.

The Idaho Research Office of the Air Resources Laboratory is studying the effect of long-period trends in atmospheric motions upon the diffusion capacity of the atmosphere. Initial indications are that concentrations at a given distance from the source are inversely proportional to about the fifth root of the sampling time. The Idaho group has also made significant progress in its studies of the surface deposition of airborne material. The studies relate both to atmospheric pollution in the normal sense of the word and to the behavior of radioactive contaminants. Work in this area is also establishing a base for expanded research in inadvertent weather modification by the increase of atmospheric pollutants.

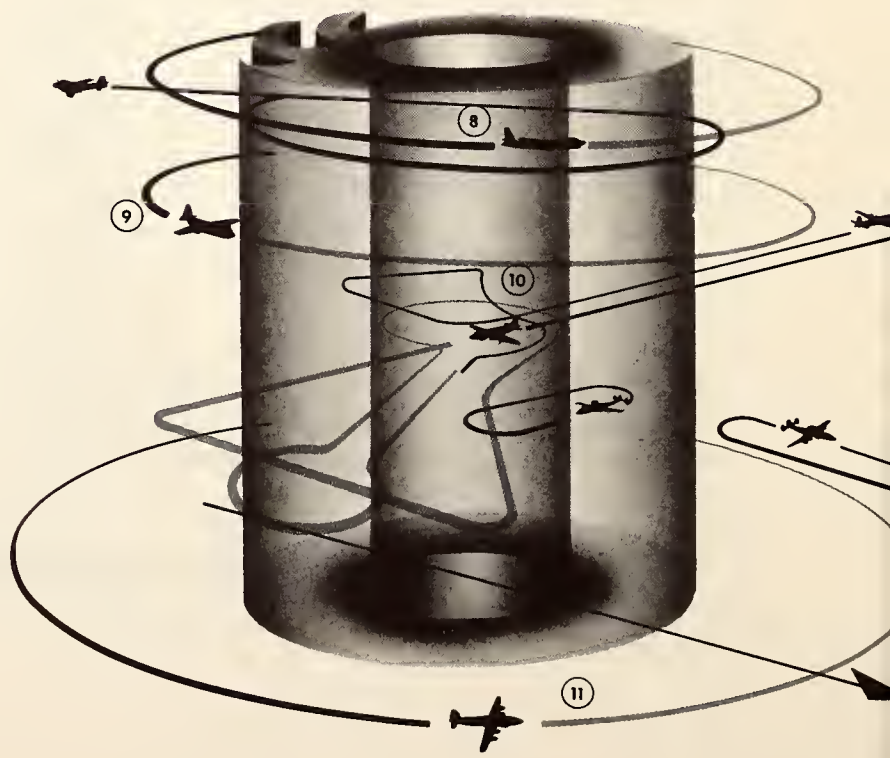


PROJECT STORMFURY's eyewall experiment involves a number of aircraft over an area of several thousand square miles, at altitudes between 1,000 and 50,000 feet. One or more aircraft are in the vicinity of the hurricane from 4 hours before seeding (T, or "Tango," for zero time) to 12 hours after seeding (Tango plus 12). This diagram shows the approximate sequence and traffic pattern in and near the storm.

The Navy WC–121 low-level inflow monitor (1) takes position 75–100 miles from the hurricane's center and 1,000 feet high at Tango minus 4. At Tango minus 3, ESSA's WB–57 (2) makes high-level outflow measurements near 40,000 feet, staying 75–100 miles from the storm center. At the same time, an ESSA DC–6 (3) begins its first penetration of the storm at 12,000 feet, gathering weather information at this intermediate level. About 75 miles from the center, the Command Control WC–121 (4) takes up an elongated flight path at 6,000 feet. Another WC–121 (5) circles in and out of the hurricane at 10,000 feet; this radar and dropsonde aircraft measures characteristics of the storm upstream of the area to be seeded. The seeding aircraft, a Navy A–6A *Intruder* (6), moves into a pattern 50 miles from the center at 35,000 feet. At Tango, the *Intruder* breaks its circular holding pattern and rams through the hurricane-force winds, dropping 80 *Alecto* canisters (7) along the path on the far side of the eye. Seeding is repeated at 2-hour intervals—at Tango plus 2, 4, 6, and 8 hours.



As the experiment progresses, an Air Force WB–47 (8) arrives to monitor high-level outflow near 40,000 feet and a C–130 cloud physics monitor (9) moves into a circular pattern at 29,000 feet, 75–100 miles from the storm center. The ESSA DC–6 which made the first penetration leaves the area, while another (10) begins its penetration. The low-level monitor heads for home as an ESSA DC–4 (11) moves into position. A WC–121 will replace it after this 4-hour patrol. At Tango plus 9, all but three aircraft return to base. Another WC–121 replaces the DC–4 as low-level inflow monitor, while an ESSA DC–6 flies the penetration pattern at 12,000 feet, and ESSA's WB–57 returns to monitor outflow at high altitudes.



MODIFICATION OF THE ENVIRONMENT

While the possibility of inadvertent weather modification is a cause for concern, there is today increasing interest in the possibility of deliberately and advantageously modifying weather processes. ESSA has established a major objective area in this field and conducts an active program to explore these possibilities, carried out through the Atmospheric Physics and Chemistry Laboratory (APCL) of the Institute for Atmospheric Sciences. Research during the reporting period fell into four main areas:

- Rain and snow modification particularly relating to Great Lakes winter storms,
- Hail modification and suppression,
- Modification of hurricanes and tropical cumulus, and
- Modification and suppression of lightning.

Rain and Snow Modification

A program to modify the rain and snowfall characteristics of winter storms over the Great Lakes is carried out through contract with several university laboratories. It is designed particularly to study storms in the early winter when the Lakes are still unfrozen and the first outbreaks of polar-continental air sweep across the warm water surface. As a result of the formation of convective clouds by surface heating from the water, large amounts of snow are precipitated along the leeward shorelines of Lakes Erie and Ontario. The shallow nature of these storms, usually topped by an inversion below 10,000 feet, makes them suitable for modification of precipitation patterns by artificial seeding. Since the same type of storm occurs in such widely scattered locations as northern Japan, the Adriatic Sea, and the Gulf Stream, results of this study will be applicable in other areas.

Research so far has been directed toward a study of the physical mechanisms of these storms. They are most intense when the air flow extends across the entire length of the lake, where they form cloud "streets" which may be 20 miles long and are usually oriented in the direction of the wind. It has been found that these cloud streets are lines of strong convergence for air originating both in Canada and in the Ohio–Illinois region. Future plans call for an expansion of both the theoretical studies of the dynamics of these storms and of the experimental seeding program. The latter will investigate the possibility of precipitation modification in order to:

- Intensify precipitation over the lake in order to release the water before the clouds reach the shoreline.
- Overseed the clouds in order to reduce precipitation over both land and water so as to redistribute the precipitation over a larger area downwind.

The direct observation of the precipitation particles which are discharged by lake winter storms relates much of the history of these storms. The existence of heavily rimed crystals indicates the correctness of the seeding hypothesis for these storms—namely, that seeding will eliminate riming which will decrease the fall velocity of the crystals and consequently redistribute their downwind fallout.

Plans are also being made to study modification of precipitation patterns over the New England States. Climatological data are being studied to provide a reference base for the coming experimental program.

Hail Modification

Early attempts to modify hail from thunderstorms have suggested that seeding may actually tend to increase hail formation, rather than decrease it, and hence any experimental seeding program must be preceded by intensive research into the mechanism of hailstorms and the formation of hailstones. From the sporadic nature of hailstorms in the United States, it follows that high mobility of equipment is required to analyze storms, and extensive use must be made of aircraft. The DC–6 airborne laboratory of ESSA's Research Flight Facility has been modified to serve as an airborne mesometeorological observatory system for this purpose, and mobility in hailstone sample collection has been achieved using a trailer-mounted cold chamber together with two radio-equipped trucks.

Two conceptual models of hail suppression are presently under study: Model I is based on a modification of the precipitation regime of the hail cloud by massive seeding, which is primarily intended to modify the development of the hail embryos. Model II is based on the depletion of the water content by generating more hailstones during the critical hail-forming period of the cloud.

While Model I would apply to any type of hailstorm, Model II applies for hailstorms which generate conical or conical-type stones. Model I will require a seeding effort which is roughly a hundred-fold that required for Model II.

Modification of Hurricanes and Tropical Cumulus

Under the aegis of Project STORMFURY, a joint ESSA–Navy program involving large-scale hurricane and cumulus cloud modification experiments, a number of randomly chosen tropical cumulus clouds were seeded with silver iodide in the Eastern Caribbean Sea area during July and August 1965 to test theoretical models and hypotheses. Their subsequent behavior was observed and recorded. The data collected during the experiments were assessed by research meteorologists of ESSA and the Naval Weather Research Facility. In a statistically significant experiment, virtually all the clouds seeded successfully were observed to grow rapidly to heights much greater than nonseeded control clouds selected from the same environments. The behavior of the seeded clouds could be divided into three categories: (1) no response, (2) cloud tops floated off, and (3) cloud development in height as well as width. Without question, the latter case is the most interesting one as it indicates that a profound modification-amplification had taken place in the cloud process. The analysis of the behavior of seeded tropical cumulus clouds, *i.e.*, the basic building blocks of disturbances, may shed much light on the dynamics of hurricanes and tropical storms to the

extent that, in the future, modification may result in retaining the beneficial effects of the precipitation without the destructive effects of high winds.

Efforts in cumulus dynamics were devoted essentially to four major topics: (1) the development of computer models for convective clouds which incorporate precipitation, (2) the continued evaluation of the 1965 cumulus seeding experiments, (3) the development of pyrotechnic seeding agents for release from aricraft, and (4) the design of a field research program jointly with the National Hurricane Research Laboratory for a study of the natural ice crystal development in maritime cumulus clouds. The work in all four areas furnishes the basis for the design of additional cumulus seeding experiments in Florida during spring 1968. These experiments will be designed to study the development of cumulus clouds after release of heat of fusion due to seeding as well as the development of the release precipitation. Special attention will be given to such cloud developments which not only cause the cloud to grow in depth but also in width. Attempts will be made to predict the cloud and precipitation development with the numerical model with the input of radiosonde and additional flight data.

Lightning Modification

The lightning suppression program of the Atmospheric Physics and Chemistry Laboratory is carried out jointly with the Army. The concept is to initiate corona discharge in a storm by seeding with radar "chaff" filaments about 10 cm. long in an effort to reduce the electric field strength and thus prevent lightning. After laboratory experiments had shown that it should be possible to produce a discharge of significant magnitude using such chaff, a series of field experiments was carried out with single-cell thunderstorms in the vicinity of Flagstaff, Ariz., during the short yearly "monsoonal" thunderstorm period from mid-July to mid-August. Even using a C–47 aircraft, which was not suitable for storm penetration, significant results were obtained. The experiments demonstrated that corona discharge is generated if chaff needles of 10 cm. length are dispersed in thunderstorm electric fields of strengths exceeding 30 kilovolts per meter, and it seems highly probable that the decay of strong electric fields is caused or accelerated by corona current produced by the chaff needles.

A Research Flight Facility DC–6 has been equipped with carefully adjusted and calibrated "field mills" designed to give the three components of the electrostatic field vector. This instrumentation will also be flown in hurricanes in order to measure the unknown electrical activities in these storms.

TELECOMMUNICATIONS ENGINEERING

For many years, the Central Radio Propagation Laboratory of NBS was the central national facility for research, development, and engineering knowledge, related to the propagation of radio waves and associated electronics systems. With the formation of ESSA, this function continues to be performed by the Institute for Telecommunication Sciences and Aeronomy (ITSA). Because of the different techniques involved, the work of the Institute in this area is divided into two major categories: ionospheric telecommunications and tropospheric telecommunications engineering.

Ionospheric Telecommunications Engineering

The growing need for telecommunications in a limited frequency spectrum has demanded the development of information for the improvement of telecommunications and utilization of the radio frequency spectrum. The program of the ITSA Ionospheric Telecommunications Laboratory in communications technology includes basic and applied research in the fields of antennas, information transmission, and frequency utilization.

Antennas

In the area of antennas, equipment used for the measurement of patterns and gains of operational antennas has been updated and improved. Data are currently being recorded on magnetic tape which can be computer-processed, saving a great deal of analysis time. Several

A probe is cleaned by electron bombardment preparatory to its use to evaluate such properties as electron density and temperature of the plasma in which it is immersed. Radio frequency resonances detected with such probes are closely related to the resonances found in the ionosphere by rockets and topside sounder satellites.

operational antennas have been measured using this updated equipment.

Antennas were designed for use with the ITSA high-power radar transmitter at Plattsville, and for the new WWV frequency standard transmitter of NBS at Fort Collins, Colo. Precise gain measurements were made on a two-element dipole antenna array which is to be used as a standard calibration antenna by the Electronic Industries Association in connection with antennas for mobile communications. A technique for the measurement of the gain of vertically polarized high-frequency antennas operating over an imperfect earth was developed. The method was tested on an antenna range using scale models. A method of making antenna gain measurements using swept-frequency techniques was also developed and has been reported in the literature.

In order to gain insight into the behavior of antenna radiation from a space vehicle during reentry, studies were made which dealt with the influence of a finite ground plane, such as a space vehicle, on the performance of an antenna. More recently, attention has been devoted to other factors, such as the influence of a plasma sheath surrounding the antenna. Currently, an effort is being made to solve these problems, utilizing meaningful boundary conditions at the boundary between the plasma and the antenna surface. One result of interest, which seems to merit further study, is that transmission through the sheath can be improved by the superposition of a strong d–c magnetic field.

Information Transmission

Experimental studies were conducted to demonstrate the relation between error rate and propagation conditions on high-frequency (HF) radio circuits using frequency shift keying modulation. An understanding of these relationships will facilitate the prediction of error rates from known propagation conditions. A study was also made of signal fading due to several components of a signal arriving at the receiver over different propagation paths.

Work is progressing on a channel simulator designed to reproduce artifically the propagation constants of a HF radio path in the laboratory. Such a simulator would greatly reduce the cost and time required to optimize HF telecommunications systems design.

General

Values of RF protection ratios required for amplitude modulation broadcasting in the HF bands for signals separated by zero and 5 kHz were determined for the International Frequency Registration Board. Operating concepts and operational procedures were studied and recommendations were made to various agencies for the improvement of their telecommunications. Standards of performance and engineering for communications systems were developed and published. In a special project to determine the effects of a post-nuclear war environment on the Nation's communications, existing communications systems were studied and models developed which characterize typical systems for use in the project.

Tropospheric Telecommunications Engineering

Research and development programs relating to engineering in the ITSA Tropospheric Telecommunications Laboratory covered the areas of spectrum utilization, the electromagnetic interference environment; and extension of useful telecommunications into the millimeter wave and optical regions of the spectrum.

Spectrum Utilization

Theoretical and experimental methods for improving various specific uses of that portion of the radio spectrum influenced primarily by the troposphere and terrain have been developed and applied in the design of various telecommunication systems. Activities include studies resulting from requirements by military and other Federal agencies in tropospheric propagation and tropospheric system analysis, and are also directly related to several ITSA mission requirements, such as studies of the propagation medium and its boundary region, studies of propagation mechanisms, and development of techniques leading toward efficient use of the spectrum. Consultative services are provided to other Federal agencies and to industry with the specific aim of guiding them toward a more proper and more efficient use of the radio-frequency spectrum, which constitutes a limited natural resource.

Of primary importance in this program area is an extensive theoretical and experimental program dealing with radio wave propagation over irregular or arbitrary terrain with low antennas at frequencies between 20 and 10,000 MHz. This study provides propagation information for compatibility problems encountered in surveillance and communications within the deployment area of a field army and has resulted so far in new data on propagation over irregular terrain. The information being gathered is also directly applicable to the more general problem of mobile communications. Within the last few years, demands on the frequency spectrum by public safety groups, industry, and other users of mobile communications systems have grown to an unforeseen extent. Results of the study of radio wave propagation characteristics over irregular terrain will aid materially in determining spectrum space requirements for various mobile services. In this way, improved allocation plans can be devised, more users can be accommodated, and the available spectrum space can be utilized more efficiently.

Results of this propagation study and of related work in point-to-point tropospheric propagation also serve as a basis for the engineering of communication links for use by the U.S. Armed Forces. While it is now possible to predict with a high degree of confidence the level of tropospheric signals transmitted over a given propagation path, much work remains to be done to predict and evaluate the limitations imposed by the propagation medium on the performance of communication systems. Appropriate studies are in progress; at this time, various

theoretical considerations are being reexamined with the aim of devising an experimental program which may include simulation studies as well as actual full-scale field tests.

Electromagnetic Interference Environment

One of the chief limitations of the utility of any communication system is the presence of other signals interfering with the desired signal. Such interference may be natural, e.g., the familiar "static" from nearby or distant thunderstorm areas, or it may be man-made. The man-made variety can be either radio or other electromagnetic noise emitted as a nuisance byproduct by electrical machinery, power lines and the like, or another communication system which intentionally or otherwise emits signals on the frequency of the desired signal. Thus, a knowledge of the interference environment is one of the basic input requirements in the economical design of a successful telecommunications network. Both natural and man-made types of interference are being studied. A project for the study of natural atmospheric radio noise has been underway for some time. The latest results are being reported in detail in ITSA publications and in summary in an extensive report to the International Radio Consultative Committee.

A greater emphasis has been directed toward the study of the second type of interference—man-made interference. Extremely limited information is available for predicting expected interference from this source. Therefore, the first step in the study was to develop means of obtaining more generally useful information about these phenomena. A newly equipped mobile laboratory possesses instrumentation for simultaneous recording of eight discrete but tunable frequencies covering the spectrum from 200 kHz through 50 MHz. Four parameters of the interference are recorded at each frequency to give not only levels but also other characteristics of the environment. The basic parameter is average power. The average voltage, the logarithm of the voltage, and the quasi-peak voltage of the envelope are recorded as deviations from the power moment. The antenna system consists of a short vertical antenna mounted in the center of the metallic roof of a specially designed semitrailer van. The roof acts as a ground plane for the recording antenna and for a stub calibrating antenna. The arrangement used allows either "fixed" location recording for the study of temporal variations of the interference environment at selected sites, or for mobile recordings for spatial studies. Because it is anticipated that rather large amounts of data will be collected with this recording system, considerable care was given to the design from the standpoint of data analysis. Because data processing techniques were essential, magnetic tape was chosen as the primary data recording method.

A number of measurements of man-made noise were made in the Washington, D.C., area. Selected locations were chosen to give an indication of expected values for urban, suburban, and normal telecommunications receiving locations. The data obtained are the beginning of a fund of basic information for the formulation of a prediction scheme for the man-made interference environment.

Millimeter Wave Propagation

Interest in this frequency range has been increasing and this program area was established to conduct theoretical and experimental research on the propagation in the troposphere of waves in the GHz frequency range (thousand million cycles per second, or about 300 mm. wave length). The objective is to study the practical usefulness of this portion of the electromagnetic spectrum, its potential for telecommunications and as a tool for probing the atmosphere.

In principle, the vertical temperature structure of the lower atmosphere can be obtained from measurements of oxygen emission spectra at millimeter wavelengths. A theoretical statistical method has been developed to evaluate information from the radiation measurements against the past history of the temperature profile. The theory of "best functions" for use in solving the radiative transfer equation has been substantially extended. The influence of cloud radiation on the temperature probe and on other systems in the 10- to 100-GHz frequency range was considered.

A theoretical program to acquire knowledge of the pressure broadening of oxygen absorption lines is in progress. A radiometer in the 50- to 60-GHz region was constructed as a preliminary step in the evaluation of a remote probe for measuring atmospheric temperatures. A radiometer operating at 10.7 GHz was constructed and installed in a 60-foot antenna for observations of noise emission from convective clouds. Models for computation of radio wave absorption in different types of rainfall were developed to aid in determining the effect on various communication systems.

Optical Propagation

Lasers permit the use of narrower and more intense beams of light at optical frequencies and of wider modulation bandwidths. The practical exploitation of these advantages for telecommunications is limited by the atmosphere, which broadens, bends, and distorts a laser beam as it traverses varying conditions. Thus, it is necessary to examine these effects, and to relate them to the observed detailed temperature structure of the air.

One immediate practical application of optical telecommunications is the precise measurement of distances of several km., which is needed for geodetic survey work. Although the time of flight of a pulse of light over such a distance may be measured precisely, the actual distance is rendered uncertain since the average density of air along the path is unknown. The possibility of reducing this uncertainty is being investigated by measuring the dispersion, i.e., by observing the difference in time of flight of pulses from two different portions of the visible spectrum. This difference is theoretically proportional to the total retardation produced by the air. A laboratory model of a two-wavelength distance-measuring device has been constructed and is presently undergoing field tests.

7 SUPPORTING FACILITIES, SERVICES, AND DEVELOPMENT ACTIVITIES

Environmental science and services require a wide variety of general and special purpose equipment, facilities, and supporting services. These include development and test facilities, stations and platforms for observing the environment, sensors, communication systems, data processing facilities, and archiving. Two of ESSA's major line components, the National Environmental Satellite Center (NESC) and the Environmental Data Service (EDS) have as their chief missions to develop and provide facilities and services to the other components of ESSA and to outside organizations; but, additionally, all components of ESSA develop and provide some common facilities as part of their assigned missions.

The purpose of this chapter is to highlight these services and facilities, both as they are used by ESSA components, and as they may assist other agencies and organizations by providing a unique capability.

DEVELOPMENT AND TEST FACILITIES

ESSA's development and test facilities provide direct support to individual component missions as well as missions cutting across component and agency lines.

Coast and Geodetic Survey

Development and test facilities operated by the Coast and Geodetic Survey (C&GS) support the fields of seismology, geomagnetism, geodesy, and marine environmental activities.

The Albuquerque Seismological Center in New Mexico is well equipped for the development of new and improved seismological instrumentation for both field and observatory application, as well as for the test and calibration of standard equipment. The specially developed low-frequency dynamic calibration unit consists of precision vertical and horizontal systems which will test all types of seismometers and vibration meters within the frequency range of .001 to 100 cycles per second to determine their dynamic response and to disclose resonant peaks or spurious signals which might distort output signal at various frequencies.

The Fredericksburg Geomagnetic Center in Corbin, Va., is maintained as a facility for the development of instruments and systems, the testing of new geomagnetic devices, the standardization and calibration of all geomagnetic instruments, and the study of special problems related to the interpretation of geomagnetic data. The Center possesses an array of Helmholz coils 20 feet in diameter. They permit the simulation of the vector magnetic field at any point on earth, or the creation of a nearly zero magnetic field for simulation of the magnetic environment in space. This facility has been used extensively by NASA for testing under simulated space conditions.

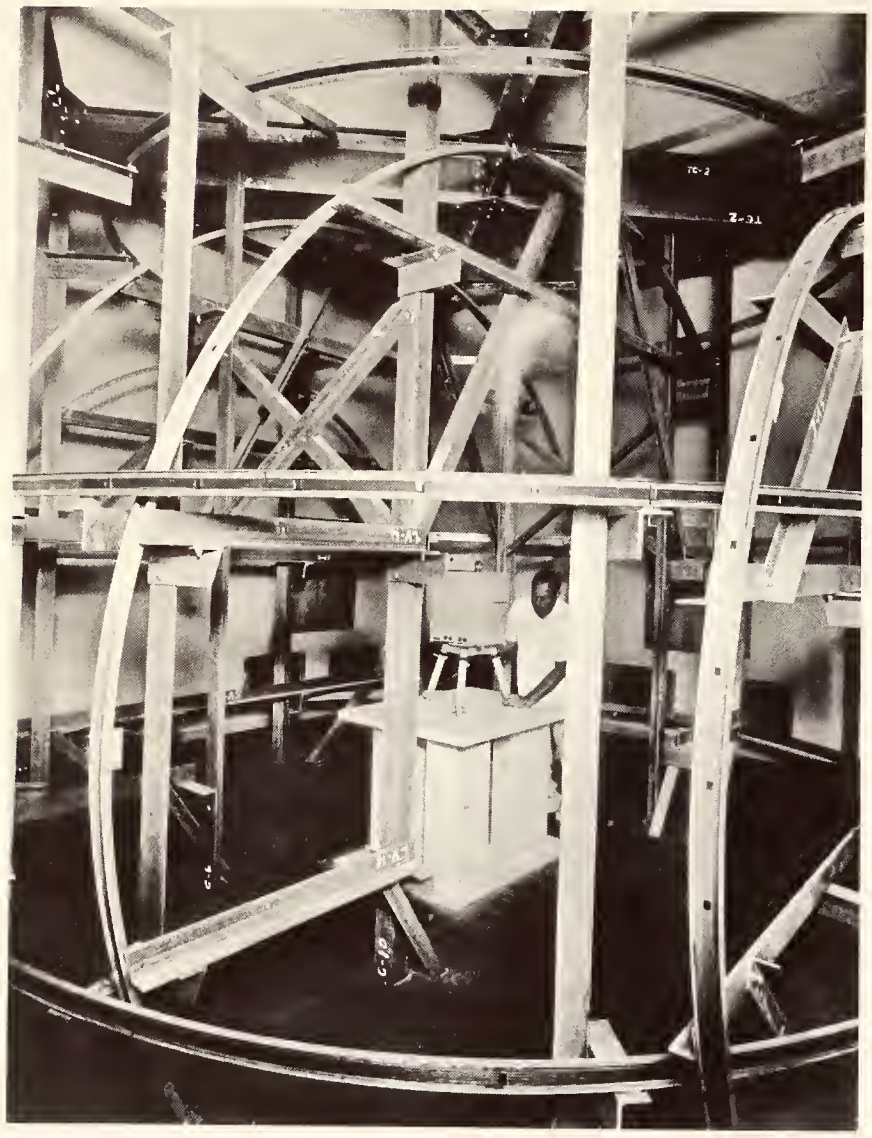
In the field of geodesy, facilities for test and calibration of new and standard instruments are maintained at a number of especially accurate control points in various parts of the United States, where location, elevation, and the strength and direction of the gravitational field are known with great precision. Underwater gravity ranges are maintained on both coasts for the calibration of shipborne equipment. A photogrammetric test and calibration range is maintained near McClure, Ohio, where both cameras and systems may be evaluated.

The Office of Geodesy and Photogrammetry of C&GS operates a laboratory at Rockville, Md., for the development of new instruments, and the Satellite Triangulation Division has established a special facility at Beltsville, Md., for development, testing, and training.

Although individual laboratories contract for the development of special purpose instruments from time to time, most development and test of oceanographic equipment is performed by the Engineering Division of C&GS, which also performs similar functions in other fields.

Weather Bureau

The Systems Development Office of the Weather Bureau in Silver Spring, Md., is responsible for all development and test of both equipment and techniques for Weather Bureau use. Two of its laboratories, the



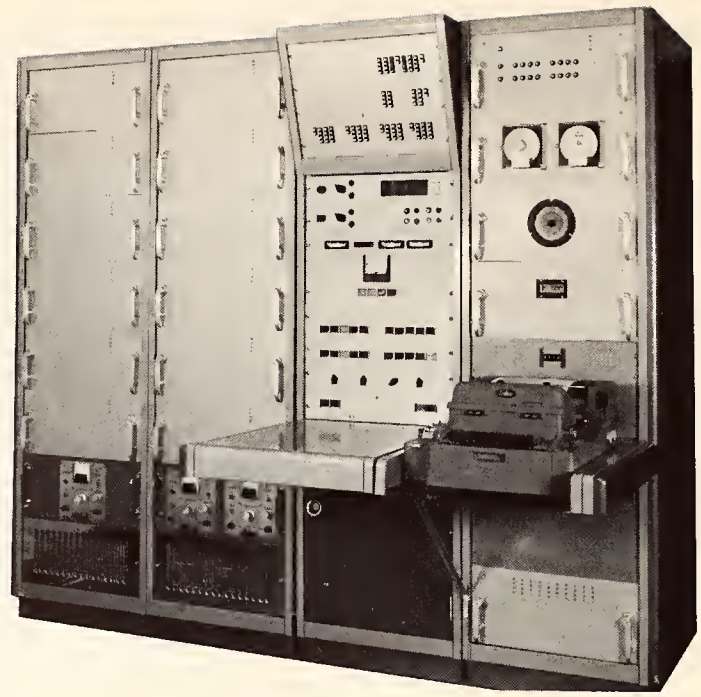
Helmholtz Coil Facility at the Fredericksburg Geomagnetic Center—Corbin, Va.

Equipment Development Laboratory and the Techniques Development Laboratory, are located with the Bureau headquarters at Silver Spring, and a third, the Test and Evaluation Laboratory, is located at Sterling, Va.

A unique facility, used in collaboration with the Federal Aviation Administration, is FAA's National Aviation Facilities Experimental Center (NAFEC), at Atlantic City, N.J. Here, by interagency agreement, the Weather Bureau has established a branch to operate an experimental weather test-bed environment. Components of the test bed include a mesometeorological network (mesonet), an upper air facility, a visual range facility, and an AMOS IV (Automatic Meteorological Observing Station) facility.

Other Elements of ESSA

Similarly, NESC maintains facilities for the development of new devices, systems, and techniques in collaboration with NASA, while the EDS seeks to improve devices and methods for the storage and retrieval of environmental data. New equipment is developed for research by all four Institutes of the Institutes for Environmental Research (IER).



An AMOS IV
(Automatic Meteorological Observing Station).

STATIONS AND PLATFORMS

ESSA observes the elements of the physical environment from a variety of stations and platforms located throughout the world. Their vantage points range from beneath the earth's surface to near space.

Land-Based Stations and Platforms

ESSA uses a large number of land-based facilities for the acquisition of environmental data, including many which are operated cooperatively with other agencies and other nations.

The 15 C&GS magnetic observatories, distributed from Alaska to the South Pole, together with more than 100 cooperating foreign observatories around the world constitute an important source of data for magnetic research and services. Usually seismological observatories are co-located with magnetic observatories, and ESSA received data from some 114 globally scattered Standard Seismograph Stations. For studying earthquake mechanisms and associated geomagnetic phenomena in detail, the Stone Canyon Geophysical Field Station, 20 miles southeast of Hollister, Calif., is now in operation. Instrumentation at this 5-acre site in the San Andreas fault zone will include: Thermally compensated earth strain meters, tiltmeters, a tripartite shallow hole seismometer array, and a magnetometer. Data will be telemetered to the Earthquake Mechanisms Laboratory of the Institute for Earth Sciences (IES) in San Francisco, where special facilities for data reduction and analysis exist.

For the purpose of detecting and measuring the largely unpredictable "wobble" of the earth about its axis of rotation for the correction of celestial navigation tables, five specially matched telescopes at different locations around the world are used to observe the stars on every

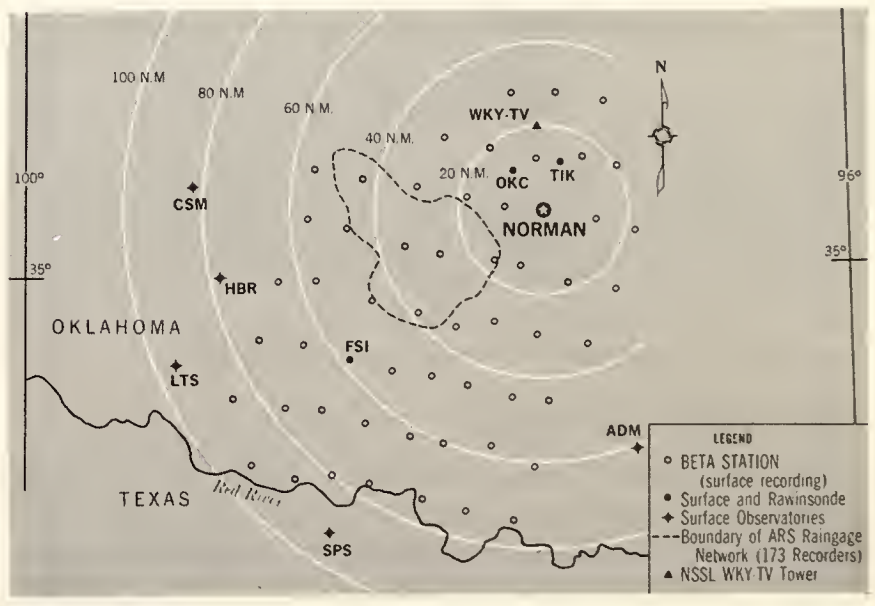
U.S. Magnetic Observatories.

clear night. Two of these stations are operated by C&GS, one at Ukiah, Calif., the other at Gaithersburg, Md.

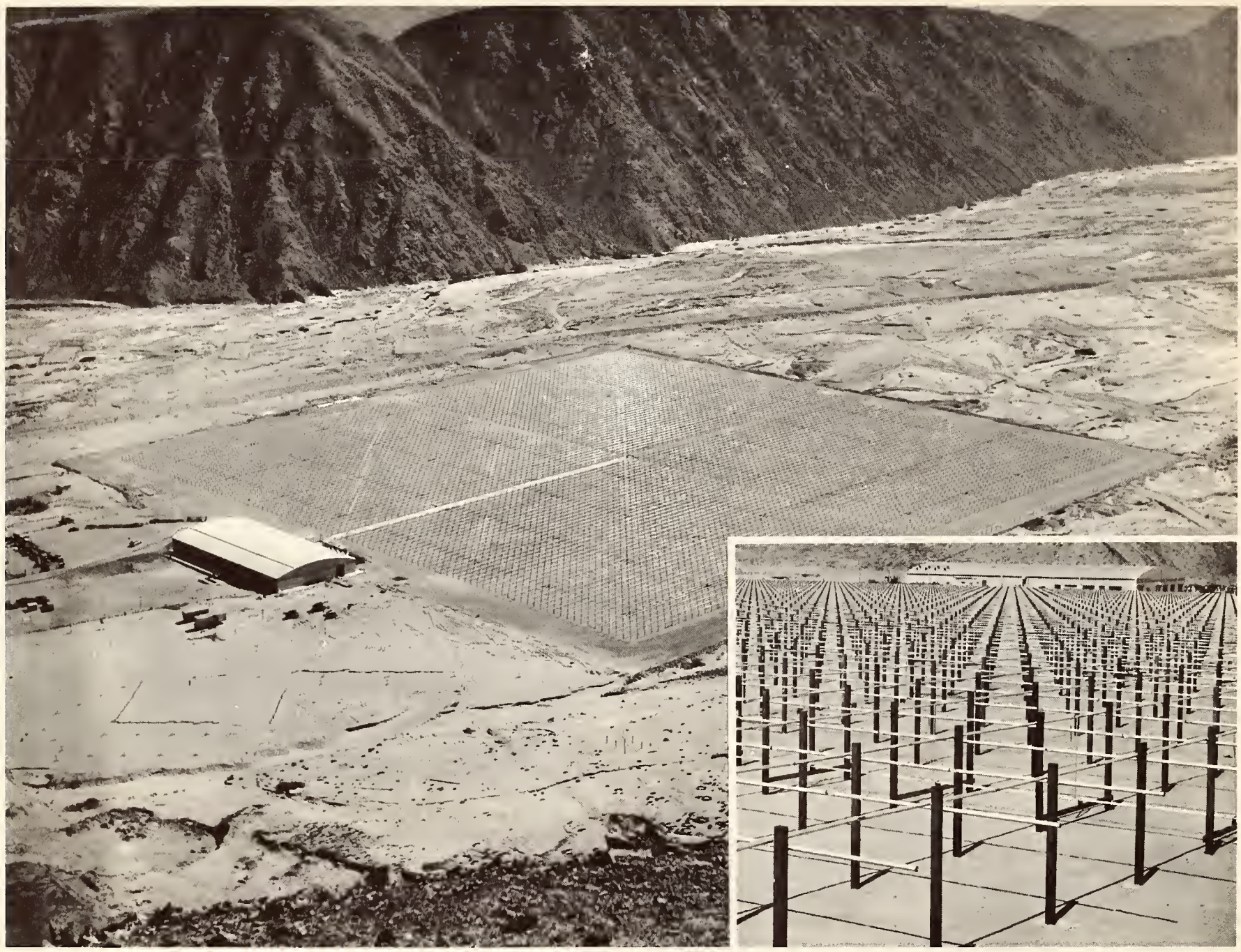
ESSA maintains a High Altitude Observatory at Mauna Loa, Hawaii, taking advantage of unusually clear air conditions to permit observations requiring this degree of atmospheric clarity. One important use is the establishment of a reference base for studies of atmospheric pollution and the monitoring of the carbon dioxide content of the air far from sources of local contamination.

The National Severe Storms Laboratory of the Institute for Atmospheric Sciences, located at Norman, Okla., operates a high-density mesometeorological network for studying tornadoes and other severe local storms. A detailed network of surface meteorological instrumentation covers some 10,000 square miles in the heart of the U.S. severe storm belt, complemented by quantitative weather radar. In addition, there is a special area of 1,100 square miles instrumented with rain gages every 2 or 3 miles; a TV tower instrumented for continuous recording of meteorological variables, including the vector wind, at six different levels; and nine radiosonde stations, included within the area. During the storm season, the ground-based network is supplemented by approximately 10 aircraft from ESSA and other agencies, for storm observation and penetration. Research is conducted on improved methods of detecting storm parameters such as rain intensity, hail, lightning, turbulence, and wind. Special emphasis has been placed on integrated radar presentations for the gathering of quantitative precipitation data, and on the Doppler radar to measure turbulence and winds aloft in storms.

ITSA operates the Jicamarca Radar Observatory, located on the geomagnetic equator near Lima, Peru. The radar antenna covers 22 acres, operating at about 50 MHz, and is used to study the upper ionosphere.



NSSL's mesometeorological network centering around Norman, Okla.



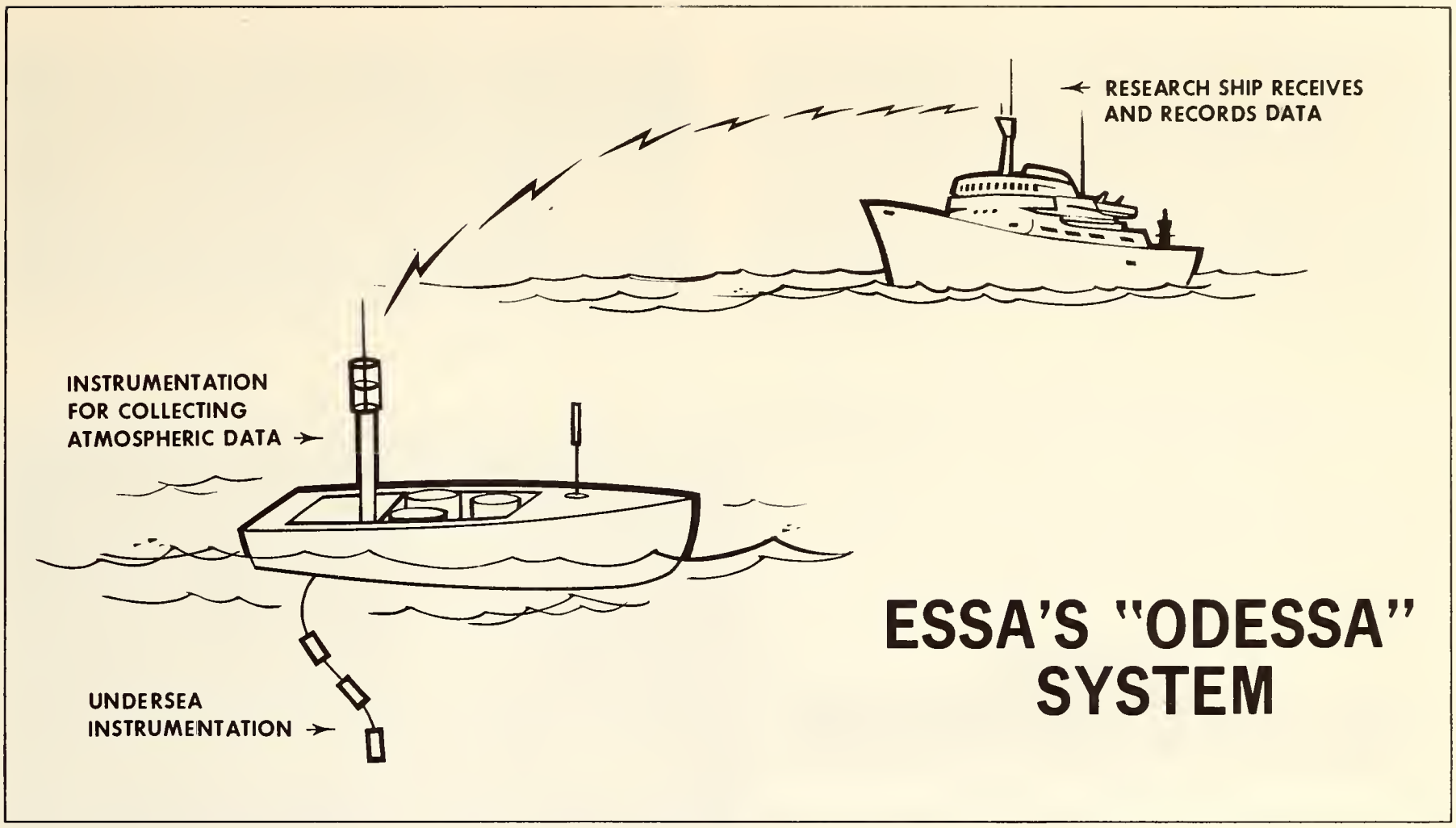
The Jicamarca Radar Observatory, an installation for ground-based observations of the upper atmosphere and outer space, is located about 17 miles east of Lima, Peru. A Peru–United States joint endeavor, the antenna is an array of dipoles some 22 acres in area. It is used in studies of the D-region of the ionosphere, and for investigations involving radio and radar astronomy.

A 15-element diffraction grating 1.5 km. in length is available for spectral analyses in this frequency region. The Observatory is used to study electron density profiles to heights of 10,000 km., electron and ion temperatures, and ionic composition to heights up to 3,000 km., and magnetic dip angles to heights of 1,000 km.

Ocean-Based Facilities

The Underwater Stable Platform, originally developed by IES personnel as a platform from which to obtain geomagnetic measurements in the ocean depths, has proved to be suitable for a variety of other measurements, including vector gravity and deep ocean tides. In the latter connection, it is of potential value in detecting the passage of tsunamis (seismic sea waves) and relaying data to the National Tsunami Warning Center.

Several buoy systems for the acquisition of oceanographic and meteorological data are in the process of development or test. The ESSA Ocean Data Acquisition System (ODESSA) is a deep-water buoy system using a line of sensors at different depths to measure oceanographic data either to be recorded on board the buoy or telemetered directly to shore receiving stations. The ODESSA System has also been adapted for use by the Navy and the Woods Hole Oceanographic Institution. A modification of this system designed specifically to measure tidal currents (TICUS) will be evaluated operationally during the coming fiscal year. Under study is the



"Odessa" electronic buoy transmits air temperature, barometric pressure, wind speed and direction, water temperature, salt content, depth, current velocity, and direction. (See right.)

feasibility of using small, lightweight, and low-cost satellite interrogated buoys to obtain ocean data on an economical, global basis.

ESSA's ocean data gathering capability is concentrated in a fleet of 15 oceanographic and hydrographic vessels operated by C&GS. A summary of the capabilities of the ships of the fleet is shown in Table 2. ESSA considers these vessels to represent an important national data acquisition resource, and encourages scientists of other agencies and institutions to make use of these facilities whenever experiments are compatible with the basic mission of a voyage. With an increasingly modernized fleet, a variety of general and special purpose instrumentation is available to measure environmental variables. Newer ships, such as the *Oceanographer*, possess automatic data logging equipment and on-board computer capability.

Five new survey ships have been delivered to C&GS during the reporting period, namely, the oceanographic survey ship, *Discoverer* (OSS–02); two hydrographic survey ships, *McArthur* (CSS–30) and *Davidson* (CSS–31); and two wire-drag ships, *Rude* (ASV–90) and *Heck* (ASV–91).

At the close of the fiscal year, five survey ships authorized under the Bureau's vessel replacement and new construction program were in the process of construction or contract negotiation:

Ship	*Class and service*	*Scheduled delivery*
MT. MITCHELL	Class II hydrographic survey	1967
FAIRWEATHER	Class II hydrographic survey	1967
RAINIER	Class II hydrographic survey	1968
RESEARCHER	Class IA ocean survey	1969
FERRELL	Class IV circulatory vessel	(Bid)

The ESSA fleet of 15 C&GS ships possesses major oceanographic survey and research capabilities. Although these ships are operated and scheduled to fulfill ESSA's missions, it is recognized that the national oceanographic effort may be enhanced by including certain projects of other organizations in the ships' schedules when these projects are compatible with ESSA's scheduled use of its fleet. Thus in January 1967, ESSA formed an Advisory Board on Allocation of Oceanographic Ship Facilities to insure maximum utilization of its oceanographic fleet and to cope with the intensity of demands and diversity of requirements for these facilities. The purpose of the Board is to review requests or proposals for ship time and to make recommendations to the Director of ESSA's Coast and Geodetic Survey concerning their use. Academic and non-profit institutions, Federal agencies, individuals, and organizations submit proposals to the Director, who then requests the advice of the Board.

C&GS SHIPS
AND THEIR CAPABILITIES

(F indicates full capability; L indicates limited capability; * indicates system on order)

	GENERAL DESCRIPTION		
	Length (ft)	Beam (ft)	Displacement (tons)
CLASS I - OCEAN SURVEY SHIP (all oceans, all climates)			
USC&GSS OCEANOGRAPHER— Based at Seattle, Washington	303	52	3885
USC&GSS DISCOVERER— Based on the East Coast	303	52	3885
USC&GSS SURVEYOR— Based at Seattle, Washington	292	46	3150
CLASS II - MEDIUM SURVEY SHIP (reduced deep ocean missions)			
USC&GSS PATHFINDER— Based at Seattle, Washington	229	39	2000
USC&GSS EXPLORER— Based at Norfolk, Virginia	219	38	1900
USC&GSS MT. MITCHELL— Based on the East Coast	231	42	1615
USC&GSS FAIRWEATHER— Based at Seattle, Washington	231	42	1615
USC&GSS RAINIER— Based at Seattle, Washington	231	42	1615
CLASS III - COASTAL SURVEY SHIP (primarily coastal waters)			
USC&GSS McARTHUR— Based at Honolulu, Hawaii	175	38	995
USC&GSS DAVIDSON— Based at Seattle, Washington	175	38	995
USC&GSS WHITING— Based at Norfolk, Virginia	162	33	760.1
USC&GSS PEIRCE— Based at Jacksonville, Florida	162	33	760.1
CLASS IV - AUXILIARY SURVEY VESSEL (limited to short periods at sea)			
USC&GSS MARMER— Based at Norfolk, Virginia	100	22	220
USC&GSS RUDE and USC&GSS HECK— Based at Norfolk, Virginia	90 90	22 22	176.4 176.4

Table 2. The annual deployment of ESSA's fleet of 15 ships affects vessels ranging from the new heavily automated *Oceanographer*, to the small wire-drag vessels *Rude* and *Heck*. At one end of this scale, Class I ocean survey vessels, with great endurance and virtually unlimited range and capability, support the research and survey efforts of ESSA. At the other end, Class IV ships, with limited range and capability, ply the Nation's coastal waters. No broader oceanographic activity or fleet exists in any other civilian agency.

An important emphasis in oceanographic research and survey programs is the interdisciplinary approach to environmental studies. The tone of activities aboard the ships of ESSA's scientific fleet was set by the global expedition of the USC&GS ship *Oceanographer*, America's largest and most completely automated oceanographic research ship. During the trip, the *Oceanographer* conducted a wide range of scientific research projects and investigations drawn up primarily by scientists of ESSA's Institute for Oceanography with the cooperation of other ESSA components, including the Coast and Geodetic Survey, the Weather Bureau, and the Institute for Telecommunication Sciences and Aeronomy.

The Board, which meets several times each year, is composed of four representatives from ESSA, one from the U.S. Geological Survey, one from the Smithsonian Institution, and two representing the academic community selected by the National Academy of Sciences.

Atmospheric Stations and Platforms

ESSA uses three *in situ* stations and platforms for studying the atmosphere—*aircraft*, *balloons*, and *rockets*.

ESSA's Research Flight Facility (RFF) of IER is located at the Miami, Fla., International Airport. Although originally established for the support of the National Hurricane Research Laboratory in its storm penetration research effort, the RFF also supports a growing number of other ESSA activities, including the National Severe Storms Laboratory (NSSL), the Atmospheric Physics and Chemistry Laboratory, and the Sea-Air Interaction Laboratory. During the reporting

NAVIGATION SYSTEMS					LABORATORIES			HYDROGRAPHIC SURVEYS					MEASUREMENTS								SPECIAL FEATURES						
															GEOLOGICAL/GEOPHYSICAL												
Satellite	Loran A	Loran C	Hifix	Raydist	Oceanographic	Meteorological	Biological	Ocean	Inshore	Launch	Wire Drag	Current Measurement	Physical Oceanographic	Biological	Magnetic Field	Gravity	Seismic Reflection Profile	Coring Heat Probe	Bottom Sampling	Automatic Data Logging	Narrow-Beam Sonar	Deep-Sea Anchoring	Deep-See Electrical Cable	Helicopter Platform	Helicopter Support	Wheel-House Control
F	F	F			F	F	L	F	L	L		L	F	L	F	F	F	F	F	F	F	F	F			F
*	F	F			F	F	L	F	L	L		L	F	L	F	F	F	F	F	F	F	F	F			F
*	F	F		F	L	L	L	F	F	F		L	F	L	F	F	F	F	F	L	F	F	F	F	L	
	F	F		L	L	L	L	F	F	F		L	F	L	F		L	F	F	L						
	F	F		F	L	L	L	F	F	F		L	F	L	F		L	F	F	L						
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The fleet works during a field season normally extending from March until November. During a season, each ship is used to full capacity; however, it has been Coast Survey policy for many years to accommodate visiting scientists from other organizations in the conduct of scientific studies aboard Coast Survey vessels. Such studies are conducted if they do not significantly interfere with the assigned operations of a given ship. This sharing improves ESSA's utilization of its research and survey fleet; more important, it opens up opportunities for field investigations not previously available to the scientific community.

Proposals for a given field season should be submitted by June 1 of the preceding year for evaluation. The proposal should describe the purpose and nature of the project, geographic area of interest, estimated ship time and equipment required, and other pertinent information—for example, whether project will be carried out by ship personnel or by personnel put aboard by the organization making the proposal. Technical papers and reports in support of the project will be useful in the Board's evaluation.

period, the RFF flew 468 missions and logged 2,391 hours of flight time using DC–6B, DC–4, and WB–57 aircraft. The aircraft possess both photographic and digital magnetic tape data logging capability.

RFF aircraft were deployed on May 4, 1967, to Tinker Air Force Base, Okla., to participate in Project ROUGH RIDER. Flights were made in support of the National Severe Storms Laboratory (NSSL) in Norman, Okla., in its program to study severe local storms over the Midwest. The basic objective of the NSSL program is to describe the kinematic and dynamic properties of severe storms by detailed measurement of meteorological parameters. This will permit the energy and water budgets of a few thunderstorm situations and the shapes of associated air circulation to be defined by analysis of the data. The mission of the RFF was to conduct airborne research operations necessary for the collection of information concerned with the moisture content and kinematic properties of air near severe thunderstorms.

During the "winter-storm" season of 1966–67, one Research Flight Facility DC–6 aircraft was used in support of a joint New York University ESSA program of study directed toward a better understanding of East Coast type storm development and snow prediction techniques. RFF aircraft collected data during two research missions which were conducted in February and March of 1967, and data collected from a dense observational network including special surface and upper air observations, radar, and satellite photographs, will be used as part of this integrated study.

RFF observations of the flight-level distribution of temperature, pressure, wind speed and direction, humidity, and the vertical distribution of temperature, pressure, and humidity (dropsonde) are of special importance since they complete the documentation of meteorological parameters over the otherwise data-sparse oceanic areas in the western Atlantic.

During the first part of the reporting period, some 2,274,000 observations were recorded for the Hurricane Laboratory, with an additional 1,090,650 data recordings in tropical storms being made for the Project STORMFURY conducted jointly by ESSA and the Department of Defense. Trajectory and dispersion studies of severe storms for NSSL produced another 520,000 observations; these efforts continued in FY 67. Other RFF efforts included a comparability study of atmospheric and oceanographic parameters with the Sea-Air Interaction Laboratory of the Institute for Oceanography, a hailstorm study with the Atmospheric Physics and Chemistry Laboratory, and a cloud photography study for the NESC.

Traditionally, the meteorologist has studied the atmosphere using balloons—either sounding balloons or constant level type. The usual sounding balloons used to carry instruments aloft range from 300 to 1,200 gm. in weight, and carry payloads up to 1,700 gm. to altitudes up to 31.5 km. The instrument packages carried by these balloons (usually radiosonde or rawinsonde) are used both for observations and data collection.

Through the National Center for Atmospheric Research, a non-profit institution supported by the National Science Foundation, large plastic constant level balloons are available for carrying heavy sensor packages to high altitudes. In addition, for various types of trajectory studies related to air pollution, ESSA has been successful in the use of another type of smaller constant level balloon, the super-pressured, tetrahedral-shaped "tetroon." Approximately 1,000 tetroons were flown during the fiscal year at altitudes from 500 feet to 12,000 feet above the surface in support of Atomic Energy Commission projects and metropolitan air pollution studies.

Another type of airborne platform employed by ESSA is the so-called Jalbert Wing. This type of parafoil has proved extremely useful in low-altitude wind and other boundary layer studies at sea because of its excellent flight characteristics and minimal support requirements.

Rockets are used by ESSA as platforms for both conventional (rocketsonde) and research telemetering sensor packages. Both endburning (Arcas) and internal burning (Asp) type rockets have been used. The Arcas can reach an altitude of about 64 km., and this height can be increased with boosters. Nike–Apache and Nike–Cajun rockets have also been launched for ESSA by NASA, carrying experimental meteorological payloads.

Space Platforms

ESSA depends on NASA for the design, development, and launching of all space platforms used in environmental research and operational systems. NESC serves as ESSA's primary point of contact with NASA for establishing data requirements, collaborating with NASA's research and development program in the field of environmental satellites, and for the definition of the design, orbit, and performance specifications for operational systems. In addition, the Center exercises day-to-day control over the ESSA operational satellites, operates the Command and Data Acquisition Stations which receive environmental satellite data, a control center to monitor and control the satellite system, and the Data Processing and Analysis Facility which processes the data and distributes it both in real time and in archival form.

In this reporting period, NASA launched five or six operational satellites for ESSA. Some of these satellites store pictures for transmission to the Command and Data Acquisition Stations at Gilmore Creek, Alaska, and Wallops Island, Va., where they are transmitted over a radio link to NESC at Suitland, Md. Others transmit local area coverage continuously to Automatic Picture Transmission (APT) stations around the globe. In addition, the Satellite Center receives data from NASA Tiros and Nimbus research satellites which complement the data received from the operational systems. Satellites of an advanced nature are planned for future years.

ENVIRONMENTAL SENSORS

ESSA uses a full complement of sensors, ranging from seismographs for detecting and measuring the vibrations of the solid earth to satellite-borne ionosondes for recording the ionosphere and its variations. Sensor and instrument development is an integral part of every research program in the environmental sciences, since in almost every area there is a need for greater sensitivity, accuracy, dependability, or scope in the making of observations. There are, however, two areas of special emphasis.

Tropospheric Remote Sensing

Meteorology has traditionally relied on *in-situ* instrumentation for data acquisition, either from surface stations, or from aircraft, balloons, and rockets. In recent years, advances in remote sensing techniques have led to new possibilities for determining meteorological variables over large geographical areas from sensors located at a distance from the area being observed, using various regions of the electromagnetic spectrum. Most of these sensors operate on the principle that the atmospheric refractive index for various regions of the radio spectrum is a function of the meteorological parameters to be measured (including temperature, density, humidity, and turbulence) and absorption, scattering, and Doppler effects.

Research in tropospheric remote-sensing techniques has a double value to ESSA. Changes in the electrical properties of the atmosphere may be used to measure meteorological variables; and at the same time, knowledge of how the atmosphere reflects, refracts, and absorbs electromagnetic radiation is of direct interest in developing methods to predict propagation conditions for telecommunications systems, or other systems relying on electromagnetic propagation. For example, at the Institutes for Environmental Research, work is proceeding on an experimental device to eliminate or reduce the effect of variations in the velocity of light due to atmospheric fluctuations, which affects the accuracy of optical distance-measuring instruments for geodesy. Similarly, when the relationship between meteorological variables and propagation is more adequately understood, it will be possible to predict propagation conditions and at the same time improve the accuracy of weather prediction through better and more widespread data acquisition.

Under the radio meteorology program, ITSA is studying the relationship between tropospheric radio wave propagation and atmospheric turbulence, water vapor content, temperature, density, and other variables. Application of the techniques developed has been made to measurements of evaporation rates inland at Lake Hefner in Oklahoma, and later application will be made to sea-air interaction studies. Other applications include the detailed study of atmospheric turbulence both in clouds and in clear air.

At the National Severe Storms Laboratory, Institute for Atmospheric Sciences, Doppler radar has been used for studies of motions in thunderstorms, for measurements of low-altitude wind velocities, and for the detection of clear-air turbulence. NSSL also uses electromagnetic propagation for the automatic detection and location of lightning discharges.

The Weather Bureau uses infrared waves in a number of advanced remote sensors. For example, an infrared cloud cover detector is used to determine cloud cover both automatically and continuously. Research is underway on the use of infrared absorption techniques to measure water vapor content in the atmosphere. This technique has several advantages over other methods: It is passive, continuous, and immediate, and the measurement directly yields the absolute humidity.

Satellite Sensors

The use of artificial satellites as instrument platforms for environmental studies has already had a major impact on meteorology and aeronomy and should eventually have similar impact on other related investigations. ESSA is concerned with the development and improvement of satellite sensors for a variety of applications. Existing operational satellite sensors are already providing a significant data input for both research and operational forecasts.

ESSA's first operational weather satellite system, the TOS System, was launched by NASA for ESSA during the reporting period. TOS satellites of the ESSA I type carry the Advanced Vidicon Camera System (AVCS). AVCS stores pictures from an entire orbit for transmission to Command and Data Acquisition Ground Stations in Virginia and Alaska. One-half inch AVCS cameras were used early in the reporting period, but 1-inch cameras have been used more recently. Television pictures are transmitted from the spacecraft as signals which are recorded on magnetic tape. These signals may be projected on special kinescopes and photographed by 35-mm. cameras. To locate the pictures geographically, latitude and longitude grids prepared by computer are electronically combined with the picture signals. In addition, the picture signals are fed directly into computers which automatically prepare picture mosaics rectified to a standard map scale suitable for direct facsimile transmission to users.

ESSA II type satellites contain two identical 1-inch APT cameras which take cloud photographs and transmit them immediately to ground receiving stations. Each of the two cameras has a wide-angle (90-degree) lens. The two cameras are mounted 180 degrees apart on the side of the spacecraft and perpendicular to the spin axis, so they point directly downward once every revolution (every 5.5 seconds). An onboard camera-triggering system programs the cameras to take pictures only when facing the earth.

The APT system automatically takes and transmits a picture every 352 seconds while the satellite is in daylight. The picture is retained on a photosensitive layer

of the vidicon tube's face during the 200-second transmission period. Images recorded by the camera are scanned line by line and sent to earth by a transistorized FM transmitter.

Each APT picture has 800 scan lines and covers an area on the earth about 2,000 statute (1,736 nautical) miles on a side when taken from an 865 statute-mile altitude. Picture resolution is about 2 statute (1.5 nautical) miles per scan line directly below the camera and about 5.2 statute (4.5 nautical) miles at the picture edge.

The satellite has two APT systems either of which, operating independently, can provide the required global coverage. This dual system will ensure a longer operational lifetime for the spacecraft. More recently launched satellites make use of both systems.

NESC is improving satellite sensing techniques, both for the atmosphere and for other elements of the environment. Examples include development, under NASA sponsorship, of a satellite infrared spectrometer, high resolution infrared imaging, and a remote sensor for measuring atmospheric ozone distribution. Plans call for the inclusion in a forthcoming TOS satellite of a solar proton and electron detector.

COMMUNICATIONS NETWORKS AND SYSTEMS

Data must be made available at central points for analysis, forecast preparation, archiving, and dissemination. As a result, ESSA necessarily maintains extensive communications networks. While it is true that not all environmental data are needed in real time, many are, and frequently on a global basis, so that ESSA not only operates a number of high-speed communications networks, but also collaborates with other agencies and nations in the transmission of data and predictions.

Fixed Communications Networks

The largest communications facilities in ESSA are those operated by the Weather Bureau. At the Bureau's National Meteorological Center (NMC) at Suitland, Md., where weather forecasts are prepared for the entire nation every 6 hours, over 50 teletype circuits are used to obtain information from weather stations around the world. Facsimile circuits now number over 15, and facsimile delivery has quadrupled in speed. As of July 1, 1966, the Numerical Weather Prediction Section of NMC, responsible for operating the highly automated national forecasting system, was preparing 254 separate teletype bulletins and 186 facsimile transmissions per day for transmission over Weather Bureau, Navy, Air Force, and foreign teletype circuits, including the Washington–Moscow data link.

Networks operated directly or on a cooperative basis by the C&GS included the Worldwide Standard Seismograph Network, a worldwide geomagnetic data network, and the tsunami warning system. The Institutes for Environmental Research, through ITSA, operate the High Altitude Nuclear Detection System and its network of communications, and a worldwide ionosonde network.

A global Solar Flare Patrol has been established under the direction of ITSA's Space Disturbance Forecast Center. The Center, in common with other elements of ESSA, makes use of the communications facilities of other agencies, in this case the U.S. Air Force and NASA.

All of these network facilities, augmented where necessary, are used for NADWARN (the nationwide Natural Disaster Warning System) to provide rapid warnings of impending natural disasters, such as hurricanes, tornadoes, floods, tsunamis, and solar disturbances.

Satellite Communications Facilities

Communications form an essential part of the NESC System for retrieving satellite data. In addition, consideration is being given to systems of data retrieval where a satellite is used, not to acquire data directly, but as a link in a communications system to retrieve data from remote surface stations, buoys and ships at sea, balloons in the atmosphere, and perhaps aircraft in flight. Plans exist for experimental programs to determine the feasibility of obtaining global data in this manner concerning meteorological and oceanographic parameters, river stages, earthquakes, and other phenomena.

COMPUTATION AND DATA FACILITIES

By June 30, 1966, ESSA had owned or leased some 26 computers for substantially full-time use, and also made use of time-sharing computers. In view of the massive quantities of data to be processed and analyzed, and the need for the modeling of complex environmental systems, this number is not surprising, and in fact, will undoubtedly grow. To insure optimum utilization of these facilities, and to provide a focus for the coordinated planning of future computer requirements, ESSA has established a Computer Division in its headquarters staff.

Coast and Geodetic Survey

The collection, analysis, compilation, and publication of geomagnetic data is a basic function of C&GS, and certain aspects of this function have now been automated. Data are collected from various observatories, digitized, and placed in a permanent data file, where they are available for many types of analysis and the preparation of geomagnetic charts.

Computers are now used in the Survey's seismology program to process seismic readings from over 600 seismograph stations to determine earthquake locations (epicenters). ESSA's work in the field of seismology provides the basic input for the tsunami warning system, and the rapid location of epicenters is essential to provide timely warning. Through the use of computers, epicenters can now be located with 70 times the former speed.

The bulk of scientific data processing for C&GS is in the fields of geodesy and photogrammetry. Geodetic computations include the adjustments of field surveys,

triangulation networks, traverses, geodimeter reductions, azimuth computations, and level networks. Computations for photogrammetry consist essentially of adjusting strips of photographs to obtain accurate geometry and data reduction for the satellite triangulation project.

During FY 66, the Atlantic Marine Center at Norfolk, Va., began use of an IBM 1130 computer to determine the basic parameters for airport obstruction charts from geodetic and photogrammetric data. Automation of this aspect of chart making has provided the public with more current and comprehensive charts. During the same time period, C&GS upgraded the use of an IBM 1620 computer-plotter system at the Pacific Marine Center at Seattle, Wash., to process raw hydrographic data directly into a *smooth sheet*, which constitutes the permanent record of a survey from which charts are made. This automation has reduced from years to months the time required to go from data acquisition to finished chart. Other ocean-related activities using computer support are tide and current predictions, harmonic anaylsis of tidal data, and studies in physical oceanography and marine geophysics.

Weather Bureau

The primary function of the National Meteorological Center of the Weather Bureau is to process worldwide meteorological observations in order to describe and forecast the state of the atmosphere. Input even today is approximately 1 million teletype words per observation cycle (12 hours) and output is approximately 100 facsimile maps, and 100,000 teletyped words of processed products enabling the smallest weather station on the facsimile and teletype networks to have rapid access to worldwide weather data.

Improvements to the system during the reporting period permitted its connection to the Air Force Automated Weather System. A modification was installed which enabled the NMC's IBM 360/30 computer to communicate in real time with an Air Force computer at Tinker Air Force Base, Okla. This connection significantly accelerated data receipt at Suitland and enabled NMC to advance its processing times by 45 minutes for upper-air data and 75 minutes for surface data.

During FY 66, NMC began use of the CDC 6600, operated by ESSA's Computer Division, to augment its new forecast model. This model provides the first computer forecast of the tropopause and jet stream levels and is the first so-called *primitive equation* model to be run under operational time schedules. This model has produced considerably improved forecasts of winds at upper levels.

The Weather Bureau's Office of Hydrology uses computers to permit more timely and complete river forecasting. Manual methods of forecasting require the full-time work of an entire River Forecast Center staff to handle a major flood. With computer support, time requirements are cut to a fraction, creating greater efficiency in the use of personnel and better forecasts, particularly under continuing flood conditions.

National Environmental Satellite Center

NESC uses three computers, including the CDC 6600, to further its mission, primarily for digitizing, calibrating, earth locating, and other processing of the incoming sensor data. A secondary activity involving computers is performance of "housekeeping" functions in the management and control of environmental satellites. In addition to producing rectified global mosaics superimposed on standard map projections, computers are used to extract quantitative abstract data for use in weather analysis and forecasting.

Environmental Data Service

The computers at the National Weather Records Center are used to further the climatological program of EDS and to perform specialized analysis of other geophysical data for clients in government and industry. The size of the EDS data bank and the need for automation can be realized by considering that about 26,000,000 data points alone are collected each year from rain gages in the United States. These data specify only one environmental parameter—basic precipitation—and it is itself an incomplete specification, since basic precipitation may require more than rain gage measurements for complete specification.

Institutes for Environmental Research

In addition to its normal use of computers, IER has specialized requirements in certain areas.

The Geophysical Fluid Dynamics Laboratory (GFDL) of the Institute for Atmospheric Sciences has been engaged in a comprehensive research program for producing more realistic and useful theoretical simulation models of the atmosphere and oceans. GFDL's program has resulted in several successful models as reported in Chapter 4 of this report, and a variety of models is now available. The advanced models simulate more properties and phenomena of the real atmosphere and oceans with greater detail and fidelity than any previously produced. Both the development of the models and their application to practical problems require the use of the most powerful and intricate electronic computers available.

In other applications of computers in IER, the High Altitude Nuclear Detection System (HANDS) program, uses a computer to analyze normal background variation in electromagnetic propagation to provide control information for the detection of high-altitude nuclear detonations. The results of these computations are also used to provide background data to the Space Disturbance Forecast Center to aid in detection of solar proton events, ionospheric disturbances from solar flares, and similar space disturbances. On-line computers are also used by both HANDS and the Forecast Center for the detection and identification of the events themselves. A com-

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puter is used to prepare forecasts of the ionosphere for telecommunications purposes.

ARCHIVING

Archiving is an essential element of ESSA research and services since it provides the base for the design of statistical prediction systems and yields information regarding cyclical and long-term changes in the environment. The basic responsibility for archiving most forms of environmental data within ESSA rests with EDS. Unlike experiments of other branches of science, environmental experiments cannot be repeated if the data are lost. Accordingly, great emphasis is placed on the development of reliable information storage and retrieval systems.

The National Weather Records Center of EDS, located in Asheville, N.C., is the national depository for worldwide climatological data while analogous functions are performed for EDS by the Space and Aeronomy Data Center at Boulder, Colo., operated by ITSA personnel.

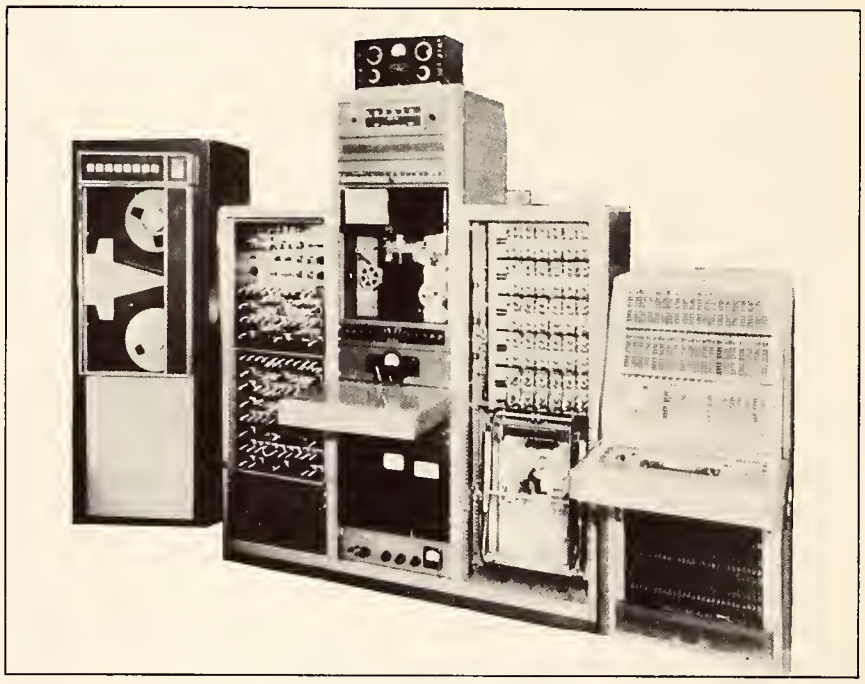
Oceanographic data are archived by the National Oceanographic Data Center, an interagency group under the direction of the Interagency Committee on Oceanography, to which ESSA contributes through EDS. The World Data Center for Geomagnetism is operated for EDS by the Coast and Geodetic Survey at Rockville, Md.

Environmental data have the unusual characteristic that they must be retained indefinitely, rather than be disposed of after the completion of an experiment. Data collected decades ago may gain new relevance in the light of recent developments. Accumulated environmental data generally tend to rise in value with time as long as they remain accessible; and hence through research and development on archiving methodology and devices, EDS attempts to assure the continued accessibility of data for the foreseeable future.

EDS has been supporting a program to develop new methods to represent or store data. The goal of this program is to develop more effective ways of processing the large amounts of raw data which are acquired, in less time, with greater user retrievability.

The storage and retrieval of data is a much more complex process than computation *per se*, since the former is concerned with meaning and value as well as with the processing of numbers. Information storage and retrieval systems require not only random access to data but access through multiple semantic channels. Particularly in interdisciplinary systems, different descriptors must be able to locate the same piece of data. As a result, such systems are more nearly analogous to card sorting systems than to the general purpose digital computer, and extensive use is, in fact, still made of punched cards.

Because of the storage and handling problems with punched cards, EDS is in the process of converting to a new system using FOSDIC (Film Optical Sensing Device for Input to Computers). The FOSDIC sensing device, together with a 16-mm. microfilm camera, constitutes a system which has greatly improved speed and efficiency. The camera is fitted to a punched card feed assembly which permits microfilming of cards at the rate of about 40,000 per hour, creating a reduction in file space of 180 to 1, and producing a film image which can be used as a direct input medium to the FOSDIC. This machine can recreate the punched cards at the rate of 100 per minute, or can selectively scan up to 10 card columns and punch only cards meeting certain specifications. The film is directly readable when magnified and can be permanently stored. A modified version of this device which will read the film electronically for direct input into a computer or storage on magnetic tape for later computer use is under development.



The FOSDIC data processing system combines the utility and convenience of punched card data retrieval systems with the compactness of a tape system. Punched cards are photographed on microfilm and retrieved by optical scanning.

No mention of ESSA's archiving facilities would be complete without a discussion of libraries. The Libraries Branch of ESSA's Scientific Information and Documentation Division operates an Atmospheric Sciences Library at Silver Spring, Md., and a Geophysical Sciences Library at Rockville. Both of these libraries offer the usual library services in their respective fields: Acquisition and preservation of books, periodicals, and other library materials; organization of materials by cataloging, indexing and shelving; and provision of library research, reference, loan, circulation, bibliographic, abstracting, and translating services. In addition, both libraries receive, store, and distribute selected ESSA publications, and coordinate the international exchange of publications within their fields. Similar functions in the field of telecommunications, aeronomy, and other aspects of geophysics are performed at Boulder by the Library Branch of IER's Scientific Documentation Division.

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ABBREVIATIONS

ACSM – American Congress on Surveying and Mapping
AEC – Atomic Energy Commission
AFOSR – Air Force Office of Scientific Research
AGU – American Geophysical Union
AMS – American Meteorological Society
APCL – Atmospheric Physics and Chemistry Laboratory, Institute for Atmospheric Sciences, ESSA

ARACON Geophysics Company—A Division of Allied Research Associates, Inc.
ARFRO—Air Resources Field Research Office
ASP—American Society of Photogrammetry
ATDL—Atmospheric Turbulence and Diffusion Laboratory, Institute for Atmospheric Sciences, ESSA
AWS—Air Weather Service, U.S. Air Force
CAT—Clear Air Turbulence
C&GS—Coast and Geodetic Survey, ESSA
C&GSTM—Coast and Geodetic Survey Technical Memorandum
COSPAR—Committee on Space Research
CWB—Contract Weather Bureau
EDL—Equipment Development Laboratory, Weather Bureau, ESSA
EML—Earthquake Mechanisms Laboratory, Institute for Earth Sciences, ESSA
EOAR—European Office of Aerospace Research, U.S. Air Force
ESSA—Environmental Science Services Administration, U.S. Department of Commerce, Rockville, Md.
FAA—Federal Aviation Administration
FDM–FM—Frequency Division Multiplex-Frequency Modulation System
GCA Corp.—Geophysical Corporation of America, Bedford, Mass.
HAO—High Altitude Observatory
HASL—Health and Safety Laboratory, Atomic Energy Commission
HF—High Frequency
HYDRO—Office of Hydrology, Weather Bureau, ESSA
IAG—International Association of Geodesy
IAMAP—International Association of Meteorology and Atmospheric Physics
IAPO—International Association of Physical Oceanography
IAS—Institute for Atmospheric Sciences, ESSA
IASH—International Association of Scientific Hydrology
IDO—Interdepartment Order (Part of an Atomic Energy Commission order)
IEEE—Institute of Electrical and Electronic Engineers
IER—Institutes for Environmental Research, ESSA, Boulder, Colo.
IERTM—Institutes for Environmental Research Technical Memorandum
IGY—International Geophysical Year
INQUA—International Quaternary
IQSY—International Years of the Quiet Sun
ITSA—Institute for Telecommunication Sciences and Aeronomy, ESSA
ITU—International Telecommunications Union
IUGG—International Union of Geodesy and Geophysics
IUWDS—International Ursigram and World Days Service
IVO—Invoice (Part of Department of Army purchasing order)
JARE—Japanese Antarctic Research Expeditions
LF/VLF—Low Frequency/Very Low Frequency
NASA—National Aeronautics and Space Administration
NATO—North Atlantic Treaty Organization
NAVAER—Office of Naval Aerospace Research
NAVOCEANO—U.S. Naval Oceanographic Office
NBA—Radio Station NBA, Balboa, Panama, Canal Zone
NBS—National Bureau of Standards
NCAPC—National Center for Air Pollution Control
NCAR—National Center for Atmospheric Research, University Corporation for Atmospheric Research, Boulder, Colo.
NESC—National Environmental Satellite Center, ESSA
NHRL—National Hurricane Research Laboratory, Institute for Atmospheric Sciences, ESSA
NMC—National Meteorological Center, Weather Bureau, ESSA
NONR—Navy Office of Naval Research
NSF—National Science Foundation
NSG—National Science Foundation Grant
NSSL—National Severe Storms Laboratory, Institute for Atmospheric Sciences, ESSA
OAR—Office of Aerospace Research, U.S. Air Force
POL—Physical Oceanography Laboratory, Institute for Oceanography, ESSA
PSW—Pacific Southwest Forest Range Experiment Station, U.S. Forest Service
REEP—Regression Estimation of Event Probabilities
SAO—Smithsonian Institute Astrophysical Observatory, Cambridge, Mass.
SDO—Systems Development Office, Weather Bureau, ESSA
SHF—Superhigh Frequency
SP—Special Publication
SRDS—Systems Research and Development Service
SRI—Stanford Research Institute, Menlo Park, Calif.
T&EL—Test and Evaluation Laboratory, Weather Bureau, ESSA
TDL—Techniques Development Laboratory, Weather Bureau, ESSA
TELECOM—TELECOM, Inc., Arlington, Va.
TM—Technical Memorandum
TN—Technical Note
TRW—Thompson, Ramo, Woolridge [Systems]
UHF—Ultrahigh Frequency
UNESCO—United Nations Educational, Scientific, and Cultural Organization
URSI—International Scientific Radio Union
USAEC—U.S. Atomic Energy Commission
USWB—U.S. Weather Bureau, ESSA
WBG—Weather Bureau Grant
WBTM—Weather Bureau Technical Memorandum
WMO—World Meteorological Organization
WSR—Weather Surveillance Radar

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